MODERN SCIENTIFIC THOUGHT

IN FOUR BOOKS: *BOOK I* BY SIR JAMES JEANS.

BOOK II BY J. B. S. HALDANE AND JULIAN HUXLEY.

BOOK III BY C. E. M. JOAD. *BOOK IV* BY H. LEVY.

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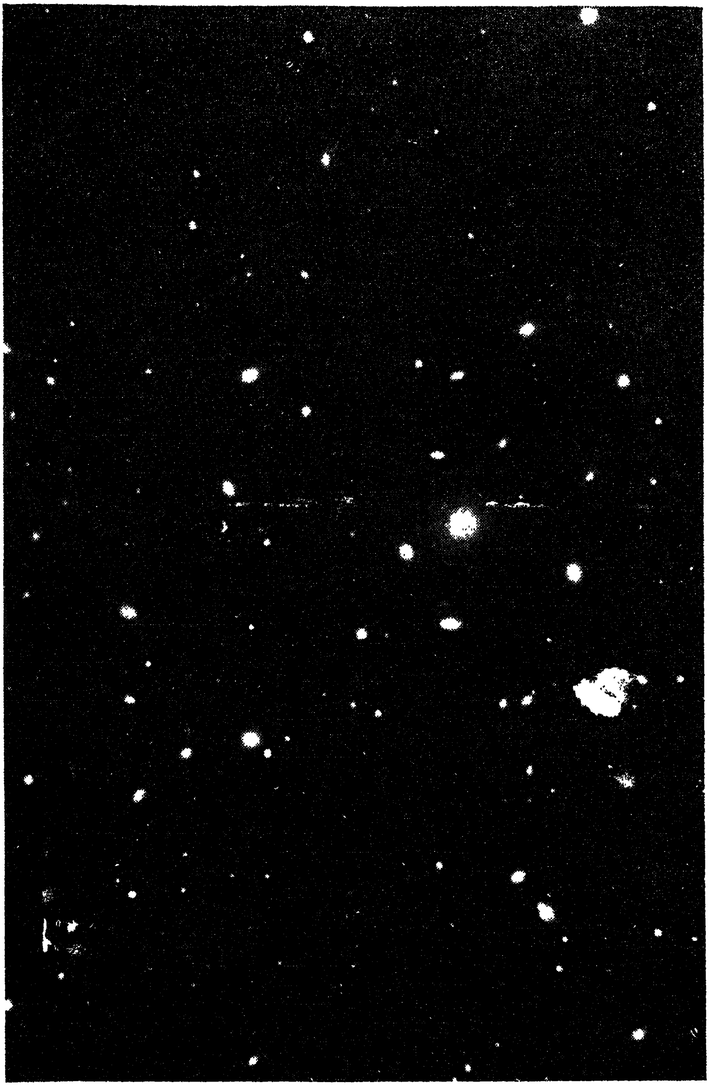
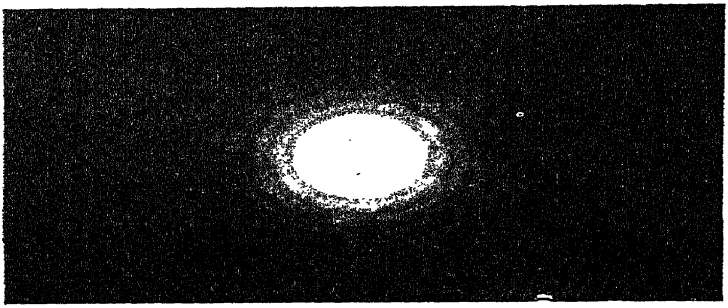
PLATE 1 OF FRONTISPIECE

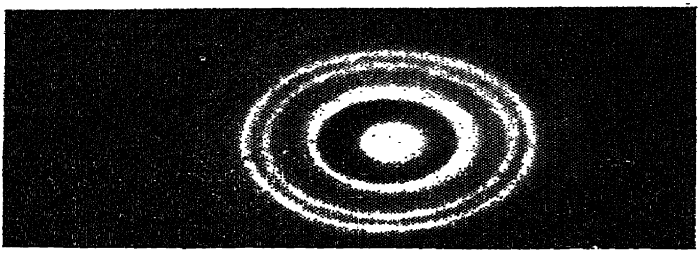


A cluster of nebulæ in Coma Berenices. This is a photograph of a minute piece of the sky, taken with the Mount Wilson telescope (100-inch). The majority of objects are nebulæ, at a distance such that their light takes fifty million years to reach us. Each nebulæ contains some thousands of millions of stars, or the material for their formation. [illegible] ut two million such nebulæ can be photographed in all, and there are probab[illegible] beyond the range of any telescope.

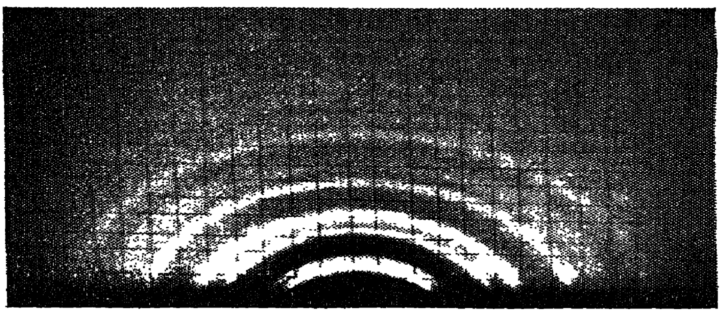
PLATE 2 OF FRONTISPIECE



(i) Diffraction rings produced by light passing through a minute aperture (a pinhole) in an opaque screen. (L. R. Wilberforce.)



(ii) Diffraction rings produced by electrons passing through a minute area of gold film. (G. P. Thomson.)



(iii) Diffraction rings produced by electrons reflected off a minute area of a gold surface. (G. P. Thomson.)

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BOOK I: THE MYSTERIOUS UNIVERSE BY SIR JAMES JEANS. *BOOK II*: ANIMAL BIOLOGY BY J. B. S. HALDANE AND JULIAN HUXLEY. *BOOK III*: THE MIND AND ITS WORKINGS BY C. E. M. JOAD. *BOOK IV*: THINKING BY H. LEVY.

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BOOK I

THE MYSTERIOUS UNIVERSE

BY SIR JAMES JEANS

And now, I said, let me show in a figure how far our nature is enlightened or unenlightened: Behold! human beings living in an underground cave, which has a mouth open towards the light and reaching all along the cave; here they have been from their childhood, and have their legs and necks chained so that they cannot move, and can only see before them, being prevented by the chains from turning round their heads. Above and behind them a fire is blazing at a distance, and between the fire and the prisoners there is a raised way; and you will see, if you look, a low wall built along the way, like the screen which marionette players have in front of them, over which they show the puppets.

I see.

And do you see, I said, men passing along the wall carrying all sorts of vessels, and statues and figures of animals made of wood and stone and various materials, which appear over the wall? . . .

You have shown me a strange image, and they are strange prisoners.

Like ourselves, I replied; and they see only their own shadows, or the other shadows which the fire throws on the opposite wall of the cave?

True, he said; how could they see anything but the shadows if they were never allowed to move their heads?

And of the objects which are being carried in like manner they would only see the shadows?

Yes, he said.

To them, I said, the truth would be literally nothing but the shadows of the images.

PLATO, REPUBLIC, BOOK VII

CHAPTER ONE

THE DYING SUN

A FEW STARS are known which are hardly bigger than the earth, but the majority are so large that hundreds of thousands of earths could be packed inside each and leave room to spare; here and there we come upon a giant star large enough to contain millions of millions of earths. And the total number of stars in the universe is probably something like the total number of grains of sand on all the seashores of the world. Such is the littleness of our home in space when measured up against the total substance of the universe.

This vast multitude of stars are wandering about in space. A few form groups which journey in company, but the majority are solitary travellers. And they travel through a universe so spacious that it is an event of almost unimaginable rarity for a star to come anywhere near to another star. For the most part each voyages in splendid isolation, like a ship on an empty ocean. In a scale model in which the stars are ships, the average ship will be well over a million miles from its nearest neighbour, whence it is easy to understand why a ship seldom finds another within hailing distance.

We believe, nevertheless, that some two thousand million years ago this rare event took place, and that a second star, wandering blindly through space, happened to come within hailing distance of the sun. Just as the sun and moon raise tides on the earth, so this second star must have raised tides on the surface of the sun. But they would be very different from the puny tides which the small mass of the moon raises in our oceans; a huge tidal wave must have travelled over the surface of the sun, ultimately forming a mountain of prodigious height, which would rise ever higher and higher as the cause of the disturbance came nearer and nearer. And, before the second star began to recede, its tidal pull had become so powerful that this mountain was torn to pieces and threw off small fragments of itself, much as the crest of a wave throws off spray. These small fragments have been circulating around their parent sun ever since. They are the planets, great and small, of which our earth is one.

The sun and the other stars we see in the sky are all intensely hot

—far too hot for life to be able to obtain or retain a footing on them. So also no doubt were the ejected fragments of the sun when they were first thrown off. Gradually they cooled, until now they have but little intrinsic heat left, their warmth being derived almost entirely from the radiation which the sun pours down upon them. In course of time, we know not how, when or why, one of these cooling fragments gave birth to life. It started in simple organisms whose vital capacities consisted of little beyond reproduction and death. But from these humble beginnings emerged a stream of life which, advancing through ever greater and greater complexity, has culminated in beings whose lives are largely centred in their emotions and ambitions, their aesthetic appreciations, and the religions in which their highest hopes and noblest aspirations lie enshrined.

Although we cannot speak with any certainty, it seems most likely that humanity came into existence in some such way as this. Standing on our microscopic fragment of a grain of sand, we attempt to discover the nature and purpose of the universe which surrounds our home in space and time. Our first impression is something akin to terror. We find the universe terrifying because of its vast meaningless distances, terrifying because of its inconceivably long vistas of time which dwarf human history to the twinkling of an eye, terrifying because of our extreme loneliness, and because of the material insignificance of our home in space—a millionth part of a grain of sand out of all the sea sand in the world. But above all else, we find the universe terrifying because it appears to be indifferent to life like our own; emotion, ambition and achievement, art and religion all seem equally foreign to its plan. Perhaps indeed we ought to say it appears to be actively hostile to life like our own. For the most part, empty space is so cold that all life in it would be frozen; most of the matter in space is so hot as to make life on it impossible; space is traversed, and astronomical bodies continually bombarded by radiation of a variety of kinds, much of which is probably inimical to, or even destructive of, life.

Into such a universe we have stumbled, if not exactly by mistake, at least as the result of what may properly be described as an accident. The use of such a word need not imply any surprise that our earth exists, for accidents will happen, and if the universe goes on for long

enough, every conceivable accident is likely to happen in time. It was, I think, Huxley who said that six monkeys, set to strum unintelligently on typewriters for millions of millions of years, would be bound in time to write all the books in the British Museum. If we examined the last page which a particular monkey had typed, and found that it had chanced, in its blind strumming, to type a Shakespeare sonnet, we should rightly regard the occurrence as a remarkable accident, but if we looked through all the millions of pages the monkeys had turned off in untold millions of years, we might be sure of finding a Shakespeare sonnet somewhere amongst them, the product of the blind play of chance. In the same way, millions of millions of stars wandering blindly through space for millions of millions of years are bound to meet with every kind of accident; a limited number are bound to meet with that special kind of accident which calls planetary systems into being. Yet calculation shows that the number of these can at most be very small in comparison with the total number of stars in the sky; planetary systems must be exceedingly rare objects in space.

This rarity of planetary systems is important, because so far as we can see, life of the kind we know on earth could only originate on planets like the earth. It needs suitable physical conditions for its appearance, the most important of which is a temperature at which substances can exist in the liquid state.

The stars themselves are disqualified by being far too hot. We may think of them as a vast collection of fires scattered throughout space, providing warmth in a climate which is at most some four degrees above absolute zero—about four hundred and eighty-four degrees of frost on our Fahrenheit scale—and is even lower in the vast stretches of space which lie out beyond the Milky Way. Away from the fires there is this unimaginable cold of hundreds of degrees of frost; close up to them there is a temperature of thousands of degrees, at which all solids melt, all liquids boil.

Life can only exist inside a narrow temperate zone which surrounds each of these fires at a very definite distance. Outside these zones life would be frozen; inside, it would be shrivelled up. At a rough computation, these zones within which life is possible, all added together, constitute less than a thousand million millionth part of the whole of

space. And even inside them, life must be of very rare occurrence, for it is so unusual an accident for suns to throw off planets as our own sun has done, that probably only about one star in 100,000 has a planet revolving round it in the small zone in which life is possible.

Just for this reason it seems incredible that the universe can have been designed primarily to produce life like our own; had it been so, surely we might have expected to find a better proportion between the magnitude of the mechanism and the amount of the product. At first glance at least, life seems to be an utterly unimportant by-product; we living things are somehow off the main line.

We do not know whether suitable physical conditions are sufficient in themselves to produce life. One school of thought holds that as the earth gradually cooled, it was natural, and indeed almost inevitable, that life should come. Another holds that after one accident had brought the earth into being, a second was necessary to produce life. The material constituents of a living body are perfectly ordinary chemical atoms—carbon, such as we find in soot or lampblack; hydrogen and oxygen, such as we find in water; nitrogen, such as forms the greater part of the atmosphere; and so on. Every kind of atom necessary for life must have existed on the new-born earth. At intervals, a group of atoms might happen to arrange themselves in the way in which they are arranged in the living cell. Indeed, given sufficient time, they would be certain to do so, just as certain as the six monkeys would be certain, given sufficient time, to type off a Shakespeare sonnet. But would they then be a living cell? In other words, is a living cell merely a group of ordinary atoms arranged in some non-ordinary way, or is it something more? Is it merely atoms, or is it atoms plus life? Or, to put it in another way, could a sufficiently skilful chemist create life out of the necessary atoms, as a boy can create a machine out of "Meccano," *and then make it go*? We do not know the answer. When it comes it will give us some indication whether other worlds in space are inhabited like ours, and so must have the greatest influence on our interpretation of the meaning of life—it may well produce a greater revolution of thought than Galileo's astronomy or Darwin's biology.

We do, however, know that while living matter consists of quite ordinary atoms, it consists in the main of atoms which have a special

capacity for coagulating into extraordinary large bunches or "molecules."

Most atoms do not possess this property. The atoms of hydrogen and oxygen, for instance, may combine to form molecules of hydrogen (H_2 or H_3), of oxygen or ozone (O_2 or O_3), of water (H_2O), or of hydrogen peroxide (H_2O_2), but none of these compounds contains more than four atoms. The addition of nitrogen does not greatly change the situation; the compounds of hydrogen, oxygen and nitrogen all contain comparatively few atoms. But the further addition of carbon completely transforms the picture; the atoms of hydrogen, oxygen, nitrogen *and carbon* combine to form molecules containing hundreds, thousands, and even tens of thousands, of atoms. It is of such molecules that living bodies are mainly formed. Until a century ago it was commonly supposed that some "vital force" was necessary to produce these and the other substances which entered into the composition of the living body. Then Wohler produced urea ($CO(NH_2)_2$), which is a typical animal product, in his laboratory, by the ordinary processes of chemical synthesis, and other constituents of the living body followed in due course. Today one phenomenon after another which was at one time attributed to "vital force" is being traced to the action of the ordinary processes of physics and chemistry. Although the problem is still far from solution, it is becoming increasingly likely that what specially distinguishes the matter of living bodies is the presence not of a "vital force," but of the quite commonplace element carbon, always in conjunction with other atoms with which it forms exceptionally large molecules.

If this is so, life exists in the universe only because the carbon atom possesses certain exceptional properties. Perhaps carbon is rather noteworthy chemically as forming a sort of transition between the metals and non-metals, but so far nothing in the physical constitution of the carbon atom is known to account for its very special capacity for binding other atoms together. The carbon atom consists of six electrons revolving around the appropriate central nucleus, like six planets revolving around a central sun; it appears to differ from its two nearest neighbours in the table of chemical elements, the atoms of boron and nitrogen, only in having one electron more than the former and one electron fewer than the latter. Yet this slight differ-

ence must account in the last resort for all the difference between life and absence of life. No doubt the reason why the six electron atom possesses these remarkable properties resides somewhere in the ultimate laws of nature, but mathematical physics has not yet fathomed it.

Other similar cases are known to chemistry. Magnetic phenomena appear in a tremendous degree in iron, and in a lesser degree in its neighbours, nickel and cobalt. The atoms of these elements have 26, 27 and 28 electrons respectively. The magnetic properties of all other atoms are almost negligible in comparison. Somehow, then, although again mathematical physics has not yet unravelled how, magnetism depends on the peculiar properties of the 26, 27 and 28 electron atoms, especially the first. Radio-activity provides a third instance, being confined, with insignificant exceptions, to atoms having from 83 to 92 electrons; again we do not know why.

Thus chemistry can only tell us to place life in the same category as magnetism and radio-activity. The universe is built so as to operate according to certain laws. As a consequence of these laws, atoms having certain definite numbers of electrons, namely 6, 26 to 28, and 83 to 92, have certain special properties, which show themselves in the phenomena of life, magnetism and radio-activity respectively. An omnipotent creator, subject to no limitation whatever, would not have been restricted to the laws which prevail in the present universe; he might have elected to build the universe to conform to any one of innumerable other sets of laws. If some other set of laws had been chosen, other special atoms might have had other special properties associated with them. We cannot say what, but it seems *a priori* unlikely that either radio-activity or magnetism or *life* would have figured amongst them. Chemistry suggests that, like magnetism and radio-activity, life may merely be an accidental consequence of the special set of laws by which the present universe is governed.

Again the word "accidental" may be challenged. For what if the creator of the universe selected one special set of laws just because they led to the appearance of life? What if this were his way of creating life? So long as we think of the creator as a magnified man-like being, activated by feelings and interests like our own, the

challenge cannot be met, except perhaps by the remark that, when such a creator has once been postulated, no argument can add much to what has already been assumed. If, however, we dismiss every trace of anthropomorphism from our minds, there remains no reason for supposing that the present laws were specially selected in order to produce life. They are just as likely, for instance, to have been selected in order to produce magnetism or radio-activity—indeed more likely, since to all appearances physics plays an incomparably greater part in the universe than biology. Viewed from a strictly material standpoint, the utter insignificance of life would seem to go far towards dispelling any idea that it forms a special interest of the Great Architect of the universe.

A trivial analogy may exhibit the situation in a clearer light. An unimaginative sailor, accustomed to tying knots, might think it would be impossible to cross the ocean if tying knots were impossible. Now the capacity for tying knots is limited to space of three dimensions; no knot can be tied in a space of 1, 2, 4, 5 or any other number of dimensions. From this fact our unimaginative sailor might reason that a beneficent creator must have had sailors under his special patronage, and have chosen that space should have three dimensions in order that tying knots and crossing the ocean should be possibilities in the universe he had created—in brief, space was of three dimensions so that there could be sailors. This and the argument outlined above seem to be much on a level, because life as a whole and the tying of knots are pretty much on a level in that neither of them forms more than an utterly insignificant fraction of the total activity of the material universe.

So much for the surprising manner in which, so far as science can at present inform us, we came into being. And our bewilderment is only increased when we attempt to pass from our origins to an understanding of the purpose of our existence, or to foresee the destiny which fate has in store for our race.

Life of the kind we know can only exist under suitable conditions of light and heat; we only exist ourselves because the earth receives the right amount of radiation from the sun; upset the balance in either direction, of excess or defect, and life must disappear from the earth. And the essence of the situation is that the balance is easily upset.

Primitive man, living in the temperate zone of the earth, must have watched the Ice Age descending on his home with something like terror; each year the glaciers came farther down into the valleys; each winter the sun seemed less able to provide the warmth needed for life. To him, as to us, the universe must have seemed hostile to life.

We of these later days, living in the narrow temperate zone surrounding our sun and peering into the far future, see an Ice Age of a different kind threatening us. Just as Tantalus, standing in a lake so deep that he only just escaped drowning, was yet destined to die of thirst, so it is the tragedy of our race that it is probably destined to die of cold, while the greater part of the substance of the universe still remains too hot for life to obtain a footing. The sun, having no extraneous supply of heat, must necessarily emit ever less and less of its life-giving radiation, and, as it does so, the temperate zone of space, within which alone life can exist, must close in around it. To remain a possible abode of life, our earth would need to move in ever nearer and nearer to the dying sun. Yet, science tells us that, so far from its moving inwards, inexorable dynamical laws are even now driving it ever farther away from the sun into the outer cold and darkness. And, so far as we can see, they must continue to do so until life is frozen off the earth, unless indeed some celestial collision or cataclysm intervenes to destroy life even earlier by a more speedy death. This prospective fate is not peculiar to our earth; other suns must die like our own, and any life there may be on other planets must meet the same inglorious end.

Physics tells the same story as astronomy. For, independently of all astronomical considerations, the general physical principle known as the second law of thermo-dynamics predicts that there can be but one end to the universe—a "heat-death" in which the total energy of the universe is uniformly distributed, and all the substance of the universe is at the same temperature. This temperature will be so low as to make life impossible. It matters little by what particular road this final state is reached; all roads lead to Rome, and the end of the journey cannot be other than universal death.

Is this, then, all that life amounts to—to stumble, almost by mistake, into a universe which was clearly not designed for life, and

which, to all appearances, is either totally indifferent or definitely hostile to it, to stay clinging on to a fragment of a grain of sand until we are frozen off, to strut our tiny hour on our tiny stage with the knowledge that our aspirations are all doomed to final frustration, and that our achievements must perish with our race, leaving the universe as though we had never been?

Astronomy suggests the question, but it is, I think, mainly to physics that we must turn for an answer. For astronomy can tell us of the present arrangement of the universe, of the vastness and vacuity of space, and of our own insignificance therein; it can even tell us something as to the nature of the changes produced by the passage of time. But we must probe deep into the fundamental nature of things before we can expect to find the answer to our question. And this is not the province of astronomy; rather we shall find that our quest takes us right into the heart of modern physical science.

CHAPTER TWO

THE NEW WORLD OF MODERN PHYSICS

PRIMITIVE MAN must have found nature singularly puzzling and intricate. The simplest phenomena could be trusted to recur indefinitely; an unsupported body invariably fell, a stone thrown into water sank, while a piece of wood floated. Yet other more complicated phenomena showed no such uniformity—the lightning struck one tree in the grove while its neighbour of similar growth and equal size escaped unharmed; one month the new moon brought fair weather, the next month foul.

Confronted with a natural world which was to all appearances as capricious as himself, man's first impulse was to create Nature in his own image; he attributed the seemingly erratic and unordered course of the universe to the whims and passions of gods, or of benevolent or malevolent lesser spirits. Only after much study did the great principle of causation emerge. In time it was found to dominate the whole of inanimate nature: a cause which could be completely isolated in its action was found invariably to produce the same effect. What happened at any instant did not depend on the volitions of extraneous beings, but followed inevitably by inexorable laws from the state of things at the preceding instant. And this state of things had in turn been inevitably determined by an earlier state, and so on indefinitely, so that the whole course of events had been unalterably determined by the state in which the world found itself at the first instant of its history; once this had been fixed, nature could move only along one road to a predestined end. In brief, the act of creation had created not only the universe but its whole future history. Man, it is true, still believed that he himself was able to affect the course of events by his own volition, although in this he was guided by instinct rather than by logic, science, or experience, but henceforth the law of causation took charge of all such events as he had previously assigned to the actions of supernatural beings.

The final establishment of this law as the primary guiding principle in nature was the triumph of the seventeenth century, the great century of Galileo and Newton. Apparitions in the sky were shown

to result merely from the universal laws of optics; comets, which had hitherto been regarded as portents of the fall of empires or the death of kings, were proved to have their motions prescribed by the universal law of gravitation. "And," wrote Newton, "would that the rest of the phenomena of nature could be deduced by a like kind of reasoning from mechanical principles."

Out of this resulted a movement to interpret the whole material universe as a machine, a movement which steadily gained force until its culmination in the latter half of the nineteenth century. It was then that Helmholtz declared that "the final aim of all natural science is to resolve itself into mechanics," and Lord Kelvin confessed that he could understand nothing of which he could not make a mechanical model. He, like many of the great scientists of the nineteenth century, stood high in the engineering profession; many others could have done so had they tried. It was the age of the engineer-scientist, whose primary ambition was to make mechanical models of the whole of nature. Waterston, Maxwell and others had explained the properties of a gas as machine-like properties with great success; the machine consisted of a vast multitude of tiny round, smooth spheres, harder than the hardest steel, flying about like a hail of bullets on a battlefield. The pressure of a gas, for instance, was caused by the impact of the speedily flying bullets; it was like the pressure which a hailstorm exerts on the roof of a tent. When sound was transmitted through a gas, these bullets were the messengers. Similar attempts were made to explain the properties of liquids and solids as machine-like properties, although with considerably less success, and also on light and gravitation—with no success at all. Yet this want of success failed to shake the belief that the universe must in the last resort admit of a purely mechanical interpretation. It was felt that only greater efforts were needed, and the whole of inanimate nature would at last stand revealed as a perfectly acting machine.

All this had an obvious bearing on the interpretation of human life. Each extension of the law of causation, and each success of the mechanical interpretation of nature, made the belief in free will more difficult. For if all nature obeyed the law of causation, why should life be exempt? Out of such considerations arose the mechanistic philosophies of the seventeenth and eighteenth centuries, and their

natural reactions, the idealist philosophies which succeeded them. Science appeared to favour a mechanistic view which saw the whole material world as a vast machine. By contrast, the idealistic view (p. 95 below) attempted to regard the world as the creation of thought and so as consisting of thought.

Until early in the nineteenth century it was still compatible with scientific knowledge to regard life as something standing entirely apart from inanimate nature. Then came the discovery that living cells were formed of precisely the same chemical atoms as non-living matter, and so were presumably governed by the same natural laws. This led to the question why the particular atoms of which our bodies and brains were formed should be exempt from the laws of causation. It began to be not only conjectured, but even fiercely maintained, that life itself must, in the last resort, prove to be purely mechanical in its nature. The mind of a Newton, a Bach or a Michelangelo, it was said, differed only in complexity from a printing press, a whistle or a steam saw; their whole function was to respond exactly to the stimuli they received from without. Because such a creed left no room for the operation of choice and free will, it removed all basis for morality. Paul did not choose to be different from Saul; he could not help being different; he was affected by a different set of external stimuli.

An almost kaleidoscopic re-arrangement of scientific thought came with the change of century. The early scientists were only able to study matter in chunks large enough to be directly apprehended by the unaided senses; the tiniest piece of matter with which they could experiment contained millions of millions of molecules. Pieces of this size undoubtedly behaved in a mechanical way, but this provided no guarantee that single molecules would behave in the same way; everyone knows the vast difference between the behaviour of a crowd and that of the individuals that compose it.

At the end of the nineteenth century it first became possible to study the behaviour of single molecules, atoms and electrons. The century had lasted just long enough for science to discover that certain phenomena, radiation and gravitation in particular, defied all attempts at a purely mechanical explanation. While philosophers were still debating whether a machine could be constructed to repro-

duce the thoughts of Newton, the emotions of Bach or the inspiration of Michelangelo, the average man of science was rapidly becoming convinced that no machine could be constructed to reproduce the light of a candle or the fall of an apple. Then, in the closing months of the century, Professor Max Planck, of Berlin, brought forward a tentative explanation of certain phenomena of radiation which had so far completely defied interpretation. Not only was his explanation non-mechanical in its nature; it seemed impossible to connect it up with any mechanical line of thought. Largely for this reason, it was criticized, attacked and even ridiculed. But it proved brilliantly successful, and ultimately developed into the modern "quantum theory," which forms one of the great dominating principles of modern physics. Also, although this was not apparent at the time, it marked the end of the mechanical age in science, and the opening of a new era.

In its earliest form, Planck's theory hardly went beyond suggesting that the course of nature proceeded by tiny jumps and jerks, like the hands of a clock. Yet, although it does not advance continuously, a clock is purely mechanical in its ultimate nature, and follows the law of causation absolutely. Einstein showed in 1917 that the theory founded by Planck appeared, at first sight at least, to entail consequences far more revolutionary than mere discontinuity. It appeared to dethrone the law of causation from the position it had heretofore held as guiding the course of the natural world. The old science had confidently proclaimed that nature could follow only one road, the road which was mapped out from the beginning of time to its end by the continuous chain of cause and effect; state *A* was inevitably succeeded by state *B*. So far the new science has only been able to say that state *A* may be followed by state *B* or *C* or *D* or by innumerable other states. It can, it is true, say that *B* is more likely than *C*, *C* than *D*, and so on; it can even specify the relative probabilities of states *B*, *C* and *D*. But, just because it has to speak in terms of probabilities, it cannot predict with certainty which state will follow which; this is a matter which lies on the knees of the gods—whatever gods there be.

A concrete example will explain this more clearly. It is known that the atoms of radium, and of other radio-active substances, dis-

integrate into atoms of lead and helium with the mere passage of time, so that a mass of radium continually diminishes in amount, being replaced by lead and helium. The law which governs the rate of diminution is very remarkable. The amount of radium decreases in precisely the same way as a population would if there were no births, and a uniform death-rate which was the same for every individual, *regardless of his age*. Or again, it decreases in the same way as the numbers of a battalion of soldiers who are exposed to absolutely random undirected fire. In brief, old age appears to mean nothing to the individual radium atom; it does not die because it has lived its life, but rather because in some way fate knocks at the door.

To take a concrete illustration, suppose that our room contains two thousand atoms of radium. Science cannot say how many of these will survive after a year's time, it can only tell us the relative odds in favour of the number being 2,000, 1,999, 1,998, and so on. Actually the most likely event is that the number will be 1,999; the probabilities are in favour of one, and only one, of the 2,000 atoms breaking up within the next year.

We do not know in what way this particular atom is selected out of the 2,000. We may at first feel tempted to conjecture it will be the atom that gets knocked about most or gets into the hottest places, or what not, in the coming year. Yet this cannot be, for if blows or heat could disintegrate one atom, they could disintegrate the other 1,999, and we should be able to expedite the disintegration of radium merely by compressing it or heating it up. Every physicist believes this to be impossible; he rather believes that every year fate knocks at the door of one radium atom in every 2,000, and compels it to break up; this is the hypothesis of "spontaneous disintegration" advanced by Rutherford and Soddy in 1903.

History, of course, may repeat itself, and once again an apparent capriciousness in nature may be found, in the light of fuller knowledge, to arise out of the inevitable operation of the law of cause and effect. When we speak in terms of probabilities in ordinary life, we merely show that our knowledge is incomplete; we may say it appears probable that it will rain tomorrow, while the meteorological expert, knowing that a deep depression is coming eastward from the Atlantic, can say with confidence that it will be wet. We may

speak of the odds on a horse, while the owner knows it has broken its leg. In the same way, the appeal of the new physics to probabilities may merely cloak its ignorance of the true mechanism of nature.

An illustration will suggest how this might be. Early in the present century, McLennan, Rutherford and others detected in the earth's atmosphere a new type of radiation, distinguished by its extremely high powers of penetrating solid matter. Ordinary light will penetrate only a fraction of an inch through opaque matter; we can shield our faces from the rays of the sun with a sheet of paper, or an even thinner screen of metal. The X-rays have a far greater penetrating power; they can be made to pass through our hands, or even our whole bodies, so that the surgeon can photograph our bones. Yet metal of the thickness of a coin stops them completely. But the radiation discovered by McLennan and Rutherford could penetrate through several yards of lead or other dense metal.

We now know that a large part of this radiation, generally described as "cosmic radiation," has its origin in outer space. It falls on the earth in large quantities, and its powers of destruction are immense. Every second it breaks up about twenty atoms in every cubic inch of our atmosphere, and millions of atoms in each of our bodies. It has been suggested that this radiation, falling on germplasm, may produce the spasmodic biological variations which the modern theory of evolution demands; it may have been cosmic radiation that turned monkeys into men.

In the same way, it was at one time conjectured that the falling of cosmic radiation on radio-active atoms might be the cause of their disintegration. The rays fell like fate, striking now one atom and now another, so that the atoms succumbed like soldiers exposed to random fire, and the law which governed their rate of disappearance was explained. This conjecture was disproved by the simple device of taking radio-active matter down a coal mine. It was now completely shielded from the cosmic rays, but continued to disintegrate at the same rate as before.

This hypothesis failed, but probably many physicists expect that some other physical agency may yet be found to act the role of fate in radio-active disintegration. The death-rate of atoms would obvi-

ously then be proportional to the strength of this agency. But other similar phenomena present far greater difficulties.

Amongst these is the familiar phenomenon of the emission of light by an ordinary electric light bulb. The essentials are that a hot filament receives energy from a dynamo and discharges it as radiation. Inside the filament, the electrons of millions of atoms are whirling round in their orbits, every now and then jumping, suddenly and almost discontinuously, from one orbit to another, sometimes emitting, and sometimes absorbing, radiation in the process. In 1917, Einstein investigated what may be described as the statistics of these jumps. Some are of course caused by the radiation itself and the heat of the filament. But these are not enough to account for the whole of the radiation emitted by the filament. Einstein found that there must be other jumps as well, and that these must occur spontaneously, like the disintegration of the radium atom. In brief, it appears as though fate must be invoked here also. Now if some ordinary physical agency played the part of fate in this case, its strength ought to affect the intensity of the emission of radiation by the filament. But, so far as we know, the intensity of the radiation depends only on known constants of nature, which are the same here as in the remotest stars. And this seems to leave no room for the intervention of an external agency.

We can perhaps form some sort of a picture of the nature of these spontaneous disintegrations or jumps, by comparing the atom to a party of four card players who agree to break up as soon as a hand is dealt in which each player receives just one complete suit. A room containing millions of such parties may be taken to represent a mass of radio-active substance. Then it can be shewn that the number of card parties will decrease according to the exact law of radio-active decay on one condition—*that the cards are well shuffled between each deal*. If there is adequate shuffling of the cards, the passage of time and the past will mean nothing to the card players, for the situation is born afresh each time the cards are shuffled. Thus the death-rate per thousand will be constant, as with atoms of radium. But if the cards are merely taken up after each deal, without shuffling, each deal follows inevitably from the preceding, and we have the analogue of the old law of causation. Here the rate of diminution in the number of players would be different from that actually observed in radio-active

disintegration. We can only reproduce this by supposing the cards to be continually shuffled, and the shuffler is he whom we have called fate.

Thus, although we are still far from any positive knowledge, it seems possible that there may be some factor, for which we have so far found no better name than fate, operating in nature to neutralize the cast-iron inevitability of the old law of causation. The future may not be as unalterably determined by the past as we used to think; in part at least it may rest on the knees of whatever gods there be.

Many other considerations point in the same direction. For instance, Professor Heisenberg has shown that the concepts of the modern quantum theory involve what he calls a "principle of indeterminacy." We have long thought of the workings of nature as exemplifying the acme of precision. Our man-made machines are, we know, imperfect and inaccurate, but we have cherished a belief that the innermost workings of the atom would exemplify absolute accuracy and precision. Yet Heisenberg now makes it appear that nature abhors accuracy and precision above all things.

According to the old science, the state of a particle, such as an electron, was completely specified when we knew its position in space at a single instant and its speed of motion through space at the same instant. These data, together with a knowledge of any forces which might act on it from outside, determined the whole future of the electron. If these data were given for all the particles in the universe, the whole future of the universe could be predicted.

The new science, as interpreted by Heisenberg, asserts that these data are, from the nature of things, unprocurable. If we know that an electron is at a certain point in space, we cannot specify exactly the speed with which it is moving—nature permits a certain "margin of error," and if we try to get within this margin, nature will give us no help: she knows nothing, apparently, of absolutely exact measurements. In the same way, if we know the exact speed of motion of an electron, nature refuses to let us discover its exact position in space. It is as though the position and motion of the electron had been marked on the two different faces of a lantern slide. If we put the slide in a bad lantern, we can focus half way between the two faces, and shall see both the position and motion of the electron toler-

ter with which the earlier physicists could experiment. It is easy to see how the illusion of determinacy—if it is an illusion—crept into science.

We have still no definite knowledge on any of these problems. A number, although I think a rapidly diminishing number, of physicists still expect that in some way the law of strict causation will in the end be restored to its old place in the natural world, but the recent trend of scientific progress gives them no encouragement. At any rate, the concept of strict causation finds no place in the picture of the universe which the new physics presents to us, with the result that this picture contains more room than did the old mechanical picture for life and consciousness to exist within the picture itself, together with the attributes which we commonly associate with them, such as free will, and the capacity to make the universe in some small degree different by our presence. For, for aught we know, or for aught that the new science can say to the contrary, the gods which play the part of fate to the atoms of our brains may be our own minds. Through these atoms our minds may perchance affect the motions of our bodies and so the state of the world around us. Today science can no longer shut the door on this possibility; she has no longer any unanswerable arguments to bring against our innate conviction of free will. On the other hand, she gives no hint as to what absence of determinism or causation may mean. If we, and nature in general, do not respond in a unique way to external stimuli, what determines the course of events? If anything at all, we are thrown back on determinism and causation; if nothing at all, how can anything ever occur?

As I see it, we are unlikely to reach any definite conclusions on these questions until we have a better understanding of the true nature of time. The fundamental laws of nature, in so far as we are at present acquainted with them, give no reason why time should flow steadily on: they are equally prepared to consider the possibility of time standing still or flowing backwards. The steady onward flow of time, which is the essence of the cause-effect relation, is something which we superpose on to the ascertained laws of nature out of our own experience; whether or not it is inherent in the nature of time, we simply do not know, although, as we shall see shortly, the theory of

relativity goes at any rate some distance towards stigmatizing this steady onward flow of time and the cause-effect relation as illusions; it regards time merely as a fourth dimension to be added to the three dimensions of space, so that *post hoc ergo propter hoc* may be no more true of a sequence of happenings in time than it is of the sequence of telegraph poles along the Great North Road.

It is always the puzzle of the nature of time that brings our thoughts to a standstill. And if time is so fundamental that an understanding of its true nature is for ever beyond our reach, then so also in all probability is a decision in the age-long controversy between determinism and free will.

The possible abolition of determinism and the law of causation from physics are, however, comparatively recent developments in the history of the quantum theory. The primary object of the theory was to explain certain phenomena of radiation, and to understand the question at issue we must retrace our steps as far back as Newton and the seventeenth century.

The most obvious fact about a ray of light, at any rate to superficial observation, is its tendency to travel in a straight line; every one is familiar with the straight edges of a sunbeam in a dusty room. As a rapidly moving particle of matter also tends to travel in a straight line, the early scientists, rather naturally, thought of light as a stream of particles thrown out from a luminous source, like shot from a gun. Newton adopted this view, and added precision to it in his "corpuscular theory of light."

Yet it is a matter of common observation that a ray of light does not always travel in a straight line. It can be abruptly turned by reflection, such as occurs when it falls on the surface of a mirror. Or its path may be bent by refraction, such as occurs when it enters water or any liquid medium; it is refraction that makes our oar look broken at the point where it enters the water, and makes the river look shallower than it proves to be when we step into it. Even in Newton's time the laws which governed these phenomena were well known. In the case of reflection the angle at which the ray of light struck the mirror was exactly the same as that at which it came off after reflection; in other words, light bounces off a mirror like a tennis ball bouncing off a perfectly hard tennis court. In the case of re-

fraction, the sine of the angle of incidence stood in a constant ratio to the sine of the angle of refraction. We find Newton at pains to show that his light-corpuscles would move in accordance with these laws, if they were subjected to certain definite forces at the surfaces of a mirror or a refracting liquid. Here are Propositions XCIV and XCVI of the *Principia* :—

PROPOSITION XCIV

If two similar mediums be separated from each other by a space terminated on both sides by parallel planes, and a body in its passage through that space be attracted or impelled perpendicularly towards either of those mediums, and not agitated or hindered by any other force; and the attraction be everywhere the same at equal distances from either plane, taken towards the same hand of the plane; I say, that the sine of incidence upon either plane will be to the sine of emergence from the other plane in a given ratio.

PROPOSITION XCVI

The same things being supposed, and that the motion before incidence is swifter than afterwards; I say, that if the line of incidence be inclined continually, the body will be at last reflected, and the angle of reflection will be equal to the angle of incidence.

Newton's corpuscular theory met its doom in the fact that when a ray of light falls on the surface of water, only part of it is refracted. The remainder is reflected, and it is this latter part that produces the ordinary reflections of objects in a lake, or the ripple of moonlight on the sea. It was objected that Newton's theory failed to account for this reflection, for if light had consisted of corpuscles, the forces at the surface of the water ought to have treated all corpuscles alike; when one corpuscle was refracted all ought to be, and this left water with no power to reflect the sun, moon or stars. Newton tried to obviate this objection by attributing "alternate fits of transmission and reflection" to the surface of the water—the corpuscle which fell on the surface at one instant was admitted, but the next instant the gates were shut, and its companion was turned away to form reflected light. This concept was strangely and strikingly anticipatory of modern quantum theory in its abandonment of the uniformity of nature and its replacement of determinism by probabilities, but it failed to carry conviction at the time.

And, in any case, the corpuscular theory was confronted by other and graver difficulties. When studied in sufficiently minute detail, light is not found to travel in such absolutely straight lines as to suggest the motions of particles. A big object, such as a house or a mountain, throws a definite shadow, and so gives as good protection from the glare of the sun as it would from a shower of bullets. But a tiny object, such as a very thin wire, hair or fibre, throws no such shadow. When we hold it in front of a screen, no part of the screen remains unilluminated. In some way the light contrives to bend round it, and, instead of a definite shadow, we see an alternation of light and comparatively dark parallel bands, known as "interference bands." To take another instance, a large circular hole in a screen lets through a circular patch of light. But make the hole as small as the smallest of pinholes, and the pattern thrown on a screen beyond is not a tiny circular patch of light, but a far larger pattern of concentric rings, in which light and dark rings alternate—"diffraction rings." Fig. 1 of *Frontispiece*, Plate II shows the pattern obtained by allowing a beam of light to pass through a pinhole on to a photographic plate. All the light which is more than a pinhole's radius from the centre has in some way bent round the edge of the hole.

Newton regarded these phenomena as evidence that his "light-corpuscles" were attracted by solid matter. He wrote:—

> The rays of light that are in our air, in their passage near the angles of bodies, whether transparent or opaque (such as the circular and rectangular edges of coins, or of knives, or broken pieces of stone or glass), are bent or inflected round those bodies, as if they were attracted to them; and those rays which in their passage came nearest to the bodies are the most inflected, as if they were most attracted.

Here again Newton was strangely anticipatory of present-day science, his supposed forces being closely analogous to the "quantum forces" of the modern wave-mechanics. But they failed to give any detailed explanation of diffraction-phenomena, and so met with no favour.

In time, all these and similar phenomena were adequately explained by supposing that light consists of waves, somewhat similar to those which the wind blows up on the sea, except that, instead of

each wave being many yards long, many thousands of waves go to a single inch. Waves of light bend round a small obstacle in exactly the way in which waves of the sea bend round a small rock. A rocky reef miles long gives almost perfect shelter from the sea, but a small rock gives no such protection—the waves pass round it on either side, and re-unite behind it, just as waves of light re-unite behind our thin hair or fibre. In the same way sea waves which fall on the entrance to a harbour do not travel in a straight line across the harbour but bend round the edges of the breakwater, and make the whole surface of the water in the harbour rough. Fig. 1 of *Frontispiece*, Plate II shows the "roughness" beyond a pinhole produced by waves of light which have bent round the edges of the pinhole like sea waves bending round a breakwater. The seventeenth century regarded light as a shower of particles, the eighteenth century, discovering that this was inadequate to account for small-scale phenomena such as we have just described, replaced the showers of particles by trains of waves.

Yet the replacement brought its own difficulties with it. When sunlight is passed through a prism, it is broken up into a rainbow-like "spectrum" of colours—red, orange, yellow, green, blue, indigo and violet. If light consisted of waves like the waves of the sea, it can be shown that all the light of the analysed sunlight ought to be found at the extreme violet end of the spectrum. Not only so, but extreme violet waves have an unlimited capacity for absorbing energy, and as they have their mouths permanently wide open, all the energy of the universe would rapidly pass into the form of violet, or ultra-violet, radiation travelling through space.

The "quantum theory" came into being as an effort to cure the wave theory of light of these defects. It has been completely successful. It has shown that Newton was not wholly wrong in regarding light as corpuscular, for it has proved that a beam of light may be regarded as broken up into discrete units, called "light-quanta" or "photons," with almost the definiteness with which a shower of rain may be broken up into drops of water, a shower of bullets into separate pieces of lead, or a gas into separate molecules.

At the same time, the light does not lose its undulatory character. Each little parcel of light has a definite quantity, of the nature of a

length, associated with it. We call this its "wave length," because when the light in question is passed through a prism, it behaves exactly as waves of this particular length of wave would do. Light of long wave length is made up of small parcels, and vice versa, the amount of energy in each parcel being inversely proportional to this wave length, so that we can always calculate the energy of a photon from its wave length, and vice versa.

It is impossible even to summarize the great mass of evidence on which these concepts are based. It all, absolutely without exception, indicates that light travels through laboratory apparatus in unbroken photons; no observation yet made has revealed the existence of a fraction of a photon, or given any reason for suspecting that such a thing can exist. Two examples may typify the whole.

Radiation may, under suitable conditions, break up the atoms on which it falls. A study of the shattered atoms discloses how much energy has been let loose on each to do the work of breaking it up. Invariably the energy proves to be exactly that of a complete photon, as calculated from its known wave length. It is as though an army of light had come into conflict with an army of matter. It has long been known that the latter army consists of individual soldiers, the atoms; it now appears that the former also consists of individual soldiers, the photons, a study of the battlefield showing that the conflict has consisted of individual man-to-man encounters.

As a second example, Professor Compton of Chicago has recently studied what happens when X-radiation falls on electrons. He finds that the radiation is scattered exactly as though it consisted of material particles of light, or photons, moving as separate detached units, this time like bullets on a battlefield, and hitting all electrons which stand in their way. The extent to which individual photons are deflected from their courses at these collisions makes it possible to calculate the energy of the photons, and again this is found to agree exactly with that calculated from their wave length.

This concept of indivisible photons again leads us back to indeterminacy. There are various methods of splitting up a beam of light into two parts which follow different paths. When the beam is reduced to a single photon, it must follow either one path or the other; it cannot distribute itself over both because the photon is indivisible.

And its choice of path proves to be a matter of probability, not of determinacy.

In this way it appears that the seventeenth century, which regarded light as mere particles, and the nineteenth century, which regarded it as mere waves, were both wrong—or, if we prefer, both right. Light, and indeed radiation of all kinds, is both particles and waves at the same time. In Professor Compton's experiments, X-radiation falls on single electrons and behaves like a shower of discrete particles; in the experiments of Laue, Bragg and others, exactly similar radiation falls on a solid crystal and behaves in all respects like a succession of waves. And it is the same throughout nature; the same radiation can simulate both particles and waves at the same time. Now it behaves like particles, now like waves; no general principle yet known can tell us what behaviour it will choose in any particular instance.

Clearly we can only preserve our belief in the uniformity of nature by making the supposition that particles and waves are in essence the same thing. And this brings us to the second, and far more exciting, half of our story. The first half, which has just been told, is that radiation can appear now as waves and now as particles; the second is that electrons and protons, the fundamental units of which all matter is composed (p. 34), can also appear now as particles, and now as waves. A duality has recently been discovered in the nature of electrons and protons similar to that already known to exist in the nature of radiation; these also appear to be particles and waves at the same time.

When Newton's corpuscular theory of light first gave place to the undulatory theory, it became necessary to explain how a succession of waves could simulate the behaviour of a shower of particles, and move in a straight line except where it was deflected from its course by reflection or refraction. For if the sunbeam let in through a crack in the shutter consisted of waves, it was natural to expect that they would spread through the whole of the room, just as a ripple spreads over the whole surface of a pond, or as the very narrow beam which has passed through a pinhole has spread out in Fig. 1 of *Frontispiece*, Plate II. Yet Young and Fresnel showed that an undisturbed succession of waves of sufficient width would move as a beam, without appreciable sideways spread—like a shower of freely moving parti-

cles—and would be reflected from a mirror in the same way in which a projectile bounces off a perfectly hard surface. It was also shown that such a system of waves would be refracted according to the known laws of refraction of light. Finally, if such a system of waves travelled through a medium whose refracting power changed continuously, its path would be similar to that of a particle which was made to deviate from a straight path by continuously acting forces. Indeed the two paths could be made identical by taking the force at every point proportional to the change in the square of the refractive index. This explained the success of Newton's Propositions XCIV and XCVI which we have quoted on page 22.

Thus whatever the particles of Newton's corpuscular theory could do, a succession of waves could do the same. But, just because of their greater complexity, they were able to do more, and in every case in which the particles failed to simulate the behaviour of light, it was found that a system of waves could fill the part completely. In this way Newton's supposed particles became resolved into systems of waves.

The last few years have seen the particles of which ordinary matter is formed—i.e., protons and electrons—resolved into systems of waves in a somewhat similar way. In many circumstances, the behaviour of an electron or proton is found to be too complex to permit of explanation as the motion of a mere particle; Louis de Broglie, Schrödinger and others have accordingly tried to interpret it as the behaviour of a group of waves and, in so doing, have founded the branch of mathematical physics which is now known as "Wave-Mechanics."

If we watch an ordinary tennis ball bouncing off the surface of a perfectly hard tennis court, we shall find that its motion is the same as that of a beam of light reflected at the surface of a mirror, so that we may properly speak of the ball as being "reflected" from the surface of the court. But there is not much gained by the discovery. No doubt it would permit us to interpret a tennis ball as a system of waves if we desired to do so, but we do not; for one thing we can see, or think we can see, that a tennis ball is not a system of waves.

The case would be different if the moving object were not a tennis ball but an electron. If the motion of an electron bouncing off a sur-

face were observed to be like that of a system of waves, nothing could preclude the possibility of the electron being a system of waves. No one can now say "This does not interest me—I can see the electron, and it clearly is not a system of waves," for no one has ever seen an electron, or has the remotest conception as to what it would look like. We are just as free *a priori* to consider an electron as a system of waves, as to consider Newton's light-corpuscles as systems of waves. And to find out whether an electron really is a system of waves, we must turn to phenomena in which a hard particle and a system of waves would behave differently.

Now the phenomena in which the electron did not behave at all as it was expected to, so long as it was regarded as a particle, provide precisely the group of phenomena we want, and in every case the electron is found to behave exactly like a system of waves. One particular phenomenon is that of a shower of electrons bouncing off a metal plate; they do not bounce off like a shower of hail-stones or tennis balls, but produce a diffraction pattern (p. 23) as a system of waves would do (*see Frontispiece*, Plate II, Fig. 3). And it is the same when the shower of electrons is shot through a tiny aperture; they spread laterally and produce a diffraction pattern very similar to that produced by waves of light (*see Frontispiece:* Plate II, Figs. 1 and 2). This does not of course prove that an electron actually consists of waves, but it raises the question whether a system of waves does not provide a better picture of the electron than the hard particle. Actually a system of waves provides a picture which has never yet failed to predict the behaviour of the electron, while the conception of an electron as a hard particle has failed on innumerable occasions.

The new wave-mechanics shows that a moving electron or proton ought to behave like a system of waves of quite definite wave length; this depends on the mass of the moving particle, and on its speed of motion, but on nothing else. And the wave lengths it assigns to electrons and protons moving under ordinary laboratory conditions are such as can be easily measured with ordinary laboratory apparatus.

Experiments on what may properly be described as the reflection and refraction of electrons have been performed by Davisson and Germer in America, by Professor G. P. Thomson at Aberdeen, by Rupp in Germany, by Kikuchi in Japan, and by many others. Mov-

ing electrons are shot, as a parallel beam, either on to or through a metallic surface. And in each case the effect recorded on a suitably placed photographic plate is not at all that which would be observed if the electrons behaved like a shower of small shot or other hard particles. A diffraction pattern is invariably obtained, consisting of a system of concentric rings, light and dark rings alternating. The pattern is the same as would have been produced if waves of a certain definite wave length had fallen on the metal, and when the wave length is measured it proves to be exactly that predicted by the wave-mechanics formula already mentioned. Recently Professor A. J. Dempster of Chicago has had a similar success with moving protons.

These and other experiments make it clear that the waves and wave lengths associated with moving electrons and protons are at least something more than a pure myth. Something of an undulatory nature is certainly involved, and the picture which represents moving electrons and protons as systems of waves explains their behaviour far better, both inside and outside atoms, than did the old picture which regarded them merely as charged particles.

We shall discuss the nature of these waves more fully below (p. 81). For our immediate purpose it is enough that the ingredients of matter (electrons and protons) and radiation both exhibit a dual nature. So long as science deals only with large-scale phenomena, an adequate picture can generally be obtained by supposing both to be of the nature of particles. But when science comes to closer grips with nature, and passes to the study of small-scale phenomena, matter and radiation are found equally to resolve themselves into waves.

If we want to understand the fundamental nature of the physical universe, it is to these small-scale phenomena that we must turn our attention. Here the ultimate nature of things lies hidden, and what we are finding is waves.

In this way, we are beginning to suspect that we live in a universe of waves, and nothing but waves. We shall discuss the nature of these waves below. At the moment it is enough to notice that modern science has travelled very far from the old view which regarded the universe merely as a collection of hard bits of matter in which waves of radiation occasionally appeared as an incident. And the next chapter will carry us farther along the same road.

CHAPTER THREE

MATTER AND RADIATION

In the early days of science, the unquestioning acceptance of the law of causation as a guiding principle in the natural world led to the discovery and formulation of laws of the general type "an assigned cause *A* leads to a known effect *B*." For instance the addition of heat to ice causes it to melt, or stated in more detail, heat decreases the amount of ice in the universe and increases the amount of water.

Primitive man would become acquainted with this law very easily—he had only to watch the action of the sun on hoar frost, or the effect of the long summer days on the mountain glaciers. In winter he would notice that cold changed water back into ice. At a further stage it might be discovered that the re-frozen ice was equal in amount to the original ice before melting. It would then be a natural inference that something belonging to a more general category than either water or ice had remained unaffected in amount throughout the transformation

$$\text{ice} \rightarrow \text{water} \rightarrow \text{ice}.$$

Modern physics is familiar with laws of this type, which it describes as "conservation laws." The discovery we have just attributed to primitive man is a special case of the law of conservation of matter. The law of "conservation of *X*," whatever *X* may be, means that the total amount of *X* in the universe remains perpetually the same: nothing can change *X* into something which is not *X*. Every such law is of necessity hypothetical; what it actually expresses is that nothing we have so far done has succeeded in changing the total amount of *X*. And if we have tried enough things and failed every time, it is legitimate to propound a law of conservation of *X*, at any rate as a working hypothesis.

At the end of last century, physical science recognized three major conservation laws:—

A	the conservation of		matter,
B	,,	,,	mass,
C	,,	,,	energy.

Other minor laws, such as those of the conservation of linear and angular momenta, need not enter our discussion, since they are mere deductions from the three major laws already mentioned.

Of the three major laws, the conservation of matter was the most venerable. It had been implied in the atomistic philosophy of Democritus and Lucretius, which supposed all matter to be made up of uncreatable, unalterable and indestructible atoms. It asserted that the matter content of the universe remained always the same, and the matter content of any bit of the universe or of any region of space remained the same except in so far as it was altered by the ingress or egress of atoms. The universe was a stage in which always the same actors—the atoms—played their parts, differing in disguises and groupings, but without change of identity. And these actors were endowed with immortality.

The second law, that of the conservation of mass, was of more modern growth. Newton had supposed every body or piece of substance to have associated with it an unvarying quantity, its mass, which gave a measure of its "inertia" or reluctance to change its motion. If one motor car requires twice the engine power of another to give us equal control over its motion, we say that it has twice the mass of the latter car. The law of gravitation asserts that the gravitational pulls on two bodies are in exact proportion to their masses, so that if the earth's attraction on two bodies proves to be the same, their "masses" must be the same, whence it follows that the simplest way of measuring the mass of any body is by weighing it.

In the course of time, chemistry showed that the Lucretian "atoms" had no right to their name (*ἀ-τίμνειν*, incapable of being cut). They proved not to be "uncuttable" at all, and so were henceforth called "molecules," the name "atom" being reserved for the smaller units into which the molecules could be broken up. There are many ways in which molecules may be broken up and their atoms rearranged. Mere contiguity with other molecules may suffice, as for instance when iron rusts or acid is poured on to metal. Molecules may also be broken up by burning, exploding, heating, or by the incidence of light. For instance, if a bottle of hydrogen peroxide is stood in a light place, the mere passage of light through the liquid breaks up each molecule of hydrogen peroxide (H_2O_2) into a molecule

of water (H_2O) and an atom of oxygen (O). When we take the cork out of our bottle we shall hear a "pop" caused by the escape of the oxygen gas, and find that some of the hydrogen peroxide has been changed into water. Molecules of silver bromide are also rearranged by the incidence of light, this change forming the basis of photography.

Towards the end of the eighteenth century Lavoisier believed he had found that the total weight of matter remained unaltered throughout all the chemical changes at his command. In due course the law of "conservation of mass" became accepted as an integral part of science. We know now that it is not altogether exact; the weight of the oxygen which escapes from our bottle of peroxide, added to that of the fluid which remains, is slightly greater than the weight of the original peroxide, and a photographic plate gains in weight by being exposed to the light. We shall see shortly that the law is inexact because it neglects the weight of the light absorbed by the molecules of hydrogen peroxide or silver bromide.

The third principle, that of the conservation of energy, is the most recent of all. Energy can exist in a vast variety of forms, of which the simplest is pure energy of motion—the motion of a train along a level track, or of a billiard ball over a table. Newton had shown that this purely mechanical energy is "conserved." For instance, when two billiard balls collide, the energy of each is changed, but the total energy of the two remains unaltered; one gives energy to the other, but no energy is lost or gained in the transaction. This, however, is only true if the balls are "perfectly elastic," an ideal condition in which the balls spring back from one another with the same speed with which they approached. Under actual conditions such as occur in nature, mechanical energy invariably appears to be lost; a bullet loses speed on passing through the air, and a train comes to rest in time if the engine is shut off. In all such cases heat and sound are produced. Now a long series of investigations has shown that heat and sound are themselves forms of energy. In a classical series of experiments made in 1840–1850, Joule measured the energy of heat, and tried to measure the energy of sound with the rudimentary apparatus of a violoncello string. Imperfect though his experiments were, they resulted in the recognition of "conservation of energy" as

a principle which covered all known transformations of energy through its various modes of mechanical energy, heat, sound and electrical energy. They showed in brief that energy is transformed rather than lost, an apparent loss of energy of motion being compensated by the appearance of an exactly equal energy of heat and sound; the energy of motion of the rushing train is replaced by the equivalent energy of the noise of the shrieking brakes and of the heating of wheels, brake blocks and rails.

Throughout the second half of the nineteenth century these three conservation laws stood unchallenged. The conservation of mass was supposed to be the same thing as the conservation of matter, because the mass of any body was regarded as the sum of the masses of its atoms; this of course explained simply—all too simply, as we now know—why total mass could not be altered by chemical action. But the newly discovered principle of conservation of energy stood apart from the two older laws, a thing by itself. The universe was still envisaged as a stage in which the players were atoms, each of which conserved its identity and mass through all time. To complete the picture, an entity known as energy was bandied about from one player to another, and this, like the actors themselves, was incapable of either creation or annihilation.

These three conservation laws ought of course to have been treated merely as working hypotheses, to be tested in every conceivable way and discarded as soon as they showed signs of failing. Yet so securely did they seem to be established that they were treated as indisputable universal laws. Nineteenth-century physicists were accustomed to write of them as though they governed the whole of creation, and on this basis philosophers dogmatized as to the fundamental nature of the universe.

It was the calm before the hurricane. The first rumble of the approaching storm was a theoretical investigation by Sir J. J. Thomson, which showed that the mass of an electrified body could be changed by setting it into motion; the faster such a body moved the greater its mass became, in opposition to Newton's concept of a fixed unalterable mass. For the moment, the principle of conservation of mass appeared to have abandoned science.

For a time this conclusion remained of merely academic interest;

it could not be tested observationally because ordinary bodies could neither be charged with sufficient electricity, nor set into motion with sufficient speed, for the variations of mass predicted by theory to become appreciable in amount. Then, just as the nineteenth century was drawing to a close, Sir J. J. Thomson and his followers began to break up the atom, which now proved to be no more uncuttable, and so no more entitled to the name of "atom," than the molecule to which the name had previously been attached. They were only able to detach small fragments, and even now the complete break-up of the atom into its ultimate constituents has not been fully achieved. These fragments were found to be all precisely similar, and charged with negative electricity. They were accordingly named "electrons."

These electrons are far more intensely electrified than an ordinary body can ever be. A gramme of gold beaten, as thin as it will go, into a gold leaf a yard square, can with luck be made to hold a charge of about 60,000 electrostatic units of electricity, but a gramme of electrons carries a permanent charge which is about nine million million times greater. Because of this, and because electrons can be set into motion by electrical means with speeds of more than a hundred thousand miles a second, it is easy to verify that an electron's mass varies with its speed. Exact experiments have shown that the variation is precisely that predicted by theory.

Thanks mainly to the researches of Rutherford, it has now been established that every atom is built up entirely of negatively charged electrons, and of positively charged particles called "protons"; matter proves to be nothing but a collection of particles charged with electricity. With one turn of the kaleidoscope all the sciences which deal with the properties and structure of matter have become ramifications of the single science of electricity. Before this, Faraday and Maxwell had shown that all radiation was electrical in its nature, so that the whole of physical science is now comprised within the single science of electricity.

Since every body is a collection of electrical charged particles, the theoretical investigation already mentioned shows that the mass of every moving body must vary with its speed of motion. The mass of a moving body may be regarded as made up of two parts—a fixed

part which the body retains even when at rest, known as its "rest-mass," and a variable part which depends on the speed of its motion. Both observation and theory have shown that this second part is exactly proportional to the energy of motion of the body; the masses of two electrons, or any two other bodies similar to one another, differ to just the extent to which their energies differ.

In 1905 Einstein extended this into a tremendous generalization. He showed that not only energy of motion but energy of every conceivable kind must possess mass of its own; if it were not so, the theory of relativity could not be true. In this way every observational test of the theory of relativity was made a witness to the truth of the hypothesis that energy possesses mass. Einstein's investigation showed that the mass of energy of any kind whatever depends solely on the amount of the energy to which it is exactly proportional. It is also exceedingly small. The *Mauretania* fully loaded, weighs about 50,000 tons; when she is travelling at twenty-five knots, her motion only increases her weight by about a millionth part of an ounce. The energy that a man puts into a long lifetime of heavy manual labour weighs only a 60,000th part of an ounce.

This discovery made it possible to reinstate the principle of conservation of mass. For mass is the aggregate of rest-mass and energy-mass, and as each of these is conserved separately (the former because matter is conserved, and the latter because energy is conserved), there must be a conservation of total mass. Nineteenth-century physics had regarded the conservation of mass as a consequence solely of the conservation of matter. Twentieth-century physics discovered that the conservation of energy was also involved; mass is now seen to be conserved only because matter and energy are conserved separately.

So long as atoms were regarded as permanent and indestructible —"the imperishable foundation stones of the universe," to use Maxwell's phrase—it was natural to treat them as the fundamental constituents of the universe. The universe was, in brief, a universe of atoms, radiation being of quite secondary importance. Every now and then an atom was supposed to be set in vibration, as a bell is struck, and emitted radiation for a brief time, as a bell emits sound, until it lapsed back to its normal state of quiescence. But radiation was no more regarded as a primary constituent of matter than sound

is of a carillon of bells. Incidentally this explains why it was found impossible to imagine how the sun could continue to radiate for thousands of millions of years or more. Sunlight was believed to be produced by the agitation of atoms, but no one could imagine what maintained the agitation.

The scene began to change as soon as it was recognized that the atom was built up of electrified particles. For no matter how far we retreat from an electrified particle, we cannot get outside the range of its attractions and repulsions. This shows that an electron must, in a certain sense at least, occupy the whole of space. Faraday and Maxwell made the matter more explicit than this; they pictured an electrified particle as an octopus-like structure, a small concrete body which threw out a sort of feelers or tentacles, called "lines of force," throughout the whole of space. When two electrified particles attracted or repelled one another, it was because their tentacles had somehow taken hold of one another, and pushed or pulled. These tentacles were supposed to be formed out of electric and magnetic forces, of which radiation is also formed. When an atom emitted radiation it merely discharged some of its tentacles into space, much as a porcupine is said to throw out its quills. This concept placed radiation and matter in more intimate relations than ever before.

Since all types of radiation are forms of energy, they must, in accordance with Einstein's principle, carry mass associated with them. When an atom emits radiation, its mass diminishes by the mass of the emitted radiation, just as, if a porcupine were to throw out its quills, its weight would diminish by the weight of the quills. Thus when a piece of coal is burnt, its weight is not altogether reproduced in the ashes and the smoke; we must add to these the weight of the light and heat emitted in the process of combustion. Only then will the total be exactly the weight of the original piece of coal.

As far back as 1873, Maxwell had shown that radiation would exert a pressure on any surface on which it fell. We now regard this as a necessary consequence of the fact that radiation carries mass about with it; a beam of light consists of mass moving with the speed of light—186,000 miles a second. Subsequently Lebedew observed this pressure, and Nichols found its amount to be that calculated by Maxwell. A target could be seen to flinch under the impact of the

radiation from a bright light, just as though a bullet had been fired into it. But the impact of such light as we experience on earth is extremely slight; to see the full implications of the phenomenon we must leave the earth and the physics which has been developed in terrestrial laboratories, in favour of the sky and the wider physics which we see in operation in the colossal crucibles of the stars. Heat an ordinary six-inch cannon ball up to 50 million degrees, which is the kind of temperature we expect to find at the centre of the sun or of an average star, and the radiation it emits would suffice to mow down—by its mere impact, like the jet of water from a fire hose—any one who approached within fifty miles of it. Indeed inside the stars this pressure of radiation is so large that it supports an appreciable fraction of the weight of the stars.

Calculation shows that about a ten-thousandth of an ounce of sunlight falls every minute on every square mile of land directly under the sun; it falls with the speed of light, and in being brought to rest it exerts a pressure of about 0·000,000,000,04 atmosphere on the land. The figures look absurdly small—the weight of sunshine which falls in a century is less than the weight of rain which falls in a fiftieth of a second of a heavy shower. Yet the amount is small only because a field a mile square is such a minute object in astronomical space. The total emission of radiation by the sun is almost exactly 250 million tons a minute, which is something like 10,000 times the average rate at which water flows under London Bridge. And, incidentally, if our factor of 10,000 is wrong, it is not because we do not know the exact weight of solar radiation, but because we do not know the average flow of the Thames with very great precision. Astronomical physics is a far more exact science than terrestrial hydraulics.

A certain weight of radiation falls on to the sun from other stars, but this is quite inappreciable in comparison with the weight of the radiation which streams out, so that the sun can only maintain its weight if actual matter is streaming into it at the rate of close upon 250 million tons a minute.

As the sun journeys through space it must continually sweep up stray matter in the form of odd atoms and molecules, of dust particles and of meteors. These last are small solid objects which exist in enormous numbers in the solar system, revolving around the sun in

orbits like those of the planets. Occasionally they dash into the earth's atmosphere, when the air-resistance of their earthward fall raises them to incandescence, and they appear as shooting-stars. Generally these dissolve into vapour before reaching the earth's surface; only occasionally is one massive enough to survive the disintegrating effect of this air-resistance, and it then strikes the earth in the form of a stone, known as a meteorite. These are sometimes of enormous size. The fall of a meteorite in Siberia in 1908 set up blasts of air which devastated the forests over an enormous area, while the shock of its impact on the solid earth caused waves which were recorded thousands of miles away. And a vast crater-shaped depression in Arizona, three miles in circumference, is believed to have been caused by the fall of a still larger meteorite in prehistoric times. Yet such giants are rare, and the average meteor is a puny affair, generally no larger than a cherry or a pea.

Shapley has estimated that many thousands of millions of shooting-stars enter the earth's atmosphere every day; each of these is turned into dust and vapour, and the earth's weight is correspondingly increased. An incomparably greater number must fall into the sun, measured by millions of millions per second, and these probably provide by far the largest contribution to the sun's bag of stray matter. Yet Shapley estimates that the total weight of meteoric matter falling into the sun can hardly exceed 2,000 tons a second, which is less than a 2,000th part of the weight it loses by radiation. Thus it seems fairly certain that on the balance the sun must be losing weight at a rate of very near 250 million tons a minute; it is a wasting structure, gradually disappearing before our eyes; it is melting away like an iceberg in the Gulf Stream. And the same must be true of other stars.

This conclusion accords well with the general broad facts of astronomy. Although there is no absolute proof, a large accumulation of evidence goes to show that young stars are heavier than old stars. They are not heavier merely by a few million tons, but several times heavier—often 10, 50 or even 100 times heavier. By far the simplest explanation is that the stars lose the greater part of their weight in the course of their lives. Now a simple calculation shows that the sun, losing weight at a rate of about 250 million tons a minute, would

require millions of millions of years to lose the greater part, or even a considerable part, of its weight. And, as other stars tell much the same story, we are led to assign lives of millions of millions of years to the stars in general.

We have other means of estimating the length of stellar lives. In particular, the motion of the stars in space proclaims their extreme antiquity, and again assigns to them lives of millions of millions of years. We have seen how far removed from one another in space the stars are—so far that it is very rare for two stars to approach each other at all closely. Yet if the stars have lived these tremendously long lives of millions of millions of years, each star ought to have experienced a number of fairly close approaches. The gravitational pulls which the stars would exert on one another on these occasions would not generally be intense enough to tear out planets, but would suffice to deflect the stars from their courses and change the speeds of their motions. In the case of binary systems, which consist of two separate masses moving through space in double harness like a single star, the gravitational pull of a near star would re-arrange the orbits of the two constituents of the binary star.

Now all these effects can be calculated in detail, so that we know exactly what to expect if the stars have really lived the terrifically long lives of millions of millions of years we are provisionally allotting to them. And everything we look for we find. All the anticipated effects are there, and, so far as we can tell, their magnitudes indicate that the stars have lived for millions of millions of years.

Against all this, there is evidence of another kind, which seems to point to a very different conclusion, and so must be discussed in some detail even though it is highly technical, and takes us into the most difficult part of the difficult theory of relativity.

As we shall see in the next chapter, this theory tells us that space itself is curved, much in the same way in which the surface of the earth is curved. The curvature of space is responsible for the curving of rays of light which is observed at a solar eclipse, and for the curvature in the paths of planets and comets, which we used to attribute to a "force" of gravitation. On this theory, the presence of matter does not produce "force," which is an illusion, but a curving of space. To confront our difficulties singly, let us for the moment

suppose that the presence of matter is the only cause of the bending of space. Then an empty universe, totally devoid of matter, would have its space entirely uncurved, because there would be no matter to curve it, and so would be of infinite size. As the universe is not empty, its size will be determined by the amount of matter it contains. The more matter there is in the universe, the more curved space will be, the more rapidly it will bend back on itself, and as a consequence the smaller the universe will be—just as a circle which curves rapidly is smaller than one which curves more gradually.

The well-known experiment of electrifying a soap bubble may make the concept clearer. A soap bubble, blown in the ordinary way, is allowed to rest on the plate of an electrical machine. As the machine is worked, and the bubble becomes more and more highly charged with electricity, its size increases steadily until finally it bursts. Here (apart from its final bursting) the soap bubble is analogous to the universe; its size depends on the amount of electricity it carries, just as the size of the universe depends on the amount of matter it contains. And yet there are two essential differences. The first is that a soap bubble has a certain curvature inherent in its structure, so that it is of definite and finite size, even when uncharged; the universe, on the other hand, becomes infinite in size when it is empty of matter. The second is that increasing the charge of electricity *increases* the size of the soap bubble, but increasing the amount of matter *decreases* the size of the universe—the more matter there is, the less space there is to hold it.

Einstein tried to obviate this last objection, as well as others, by making the universe more like the soap bubble. He imagined it to have an inherent curvature, besides that produced by matter, of such a kind that its size would *increase* if the amount of matter increased.

Even so, there is still one outstanding difference. The gravitating masses in space all attract one another, but the electric charges on the soap bubble repel one another, because they are all of similar electricity, whether positive or negative. As a consequence of this, the electrified soap bubble is a thoroughly stable structure. Add a little more charge and it calmly adjusts itself to a new, slightly expanded, position of equilibrium. Shake it, and, after trembling for a bit, it

settles down to rest again. But, just because of the difference between attraction and repulsion, a soap bubble charged with attracting matter would be unstable. The mathematician will see why this must be so. And although it is a long step from a two-dimensional soap bubble of liquid film to a universe, a recent investigation by a Belgian mathematician, the Abbé Lemaître, has shown that the analogy holds, and that the kind of universe we have just been discussing would be an unstable structure; it could not stay at rest for long, but would start at once to expand to infinite size or contract to a point. Hence the actual space of an aged universe ought to be either expanding or contracting, and the various objects in it all rushing away from one another, or all rushing towards one another, at a great rate.

Lemaître's conclusions are based upon Einstein's concept of a universe whose size, when at rest, depends on the amount of matter it contains. Previously to this, however, a very different concept of the universe had been put forward by Professor de Sitter, of Leiden. Like Einstein, he supposed the universe to possess a certain amount of curvature, impressed upon it by the inherent properties of space and time. The presence of matter added an additional curvature, but, as matter is so sparsely distributed in the actual universe, this was insignificant in comparison with the curvature resulting from the nature of space and time. When de Sitter studied the properties of his universe mathematically, he too found a tendency for its space to expand or contract, and for all the objects in it either to drift apart or to rush towards one another.

At first de Sitter's concept of the universe appeared to be entirely antagonistic to Einstein's earlier concept, and mathematicians were content to wait for something to decide between them. But Lemaître's work now shows that the two concepts are not so much competitive as complementary. As Einstein's unstable universe expands, the matter in it becomes more and more sparse until it ends up as an empty universe of the kind pictured by de Sitter. The universes of Einstein and de Sitter may rightly be imagined as placed at the two ends of a chain, but we shall go wrong if we imagine them engaged in a tug-of-war. They merely mark the limits of possible universes, and a universe which starts at or near the Einstein end of the chain must gradually slip along the chain to the de Sitter

end. If our universe is built on these lines at all, the question before us is not at which end of the chain it is, but how far along the chain it has travelled.

The two ideal universes at the two ends of the chain are similar in that the objects in them must be either all rushing away from one another or else all rushing towards one another. This is not only true at the two extreme ends of the chain, but all along the chain. If the universe is built in accordance with the theory of relativity, as it almost certainly is, then the objects in it must be running all away from one another or all towards one another.

These conclusions are of great interest, because it has for some years been remarked that the remote spiral nebulæ are, to all appearances, rushing away from the earth, and so presumably also from one another, at terrific speeds, which become greater and greater the farther we recede into space. The last nebula investigated at Mount Wilson—one of the most distant which can be observed in the great 100-inch telescope—was found to be receding at the terrific speed of 15,000 miles a second. Dr. Hubble and Dr. Humason, who have made a special study of the question at Mount Wilson, find that the speeds at which the individual nebulæ are receding from us are, roughly speaking, proportional to their distances from us, as they ought to be, if the cosmology of the theory of relativity is correct. A nebula whose light takes ten million years to reach us, has a speed of about 900 miles a second, and the speeds of other nebulæ are, approximately at least, proportional to their distances. For instance, the light from the nebulæ shown in Plate I takes 50 million years to reach us, and the nebulæ show speeds of recession of about 4,500 miles a second.

The actual figures are important, because if we trace the implied nebular motions backwards, we find that all the nebulæ must have been congregated in the neighbourhood of the sun only a few thousands of millions of years ago. All this goes to suggest that we are living in an expanding universe, which started to expand only a few thousands of millions of years ago.

If this were the whole story, it would be very difficult to assign ages of millions of millions of years to the stars; this would imply that they had been packed close together, or had been converging

into a small region of space, for millions of millions of years, and only just recently, during the last thousandth part or so of their existence, had begun to scatter. If the supposed motions of recession ultimately prove to be real, it will hardly be possible to attribute an age of more than a few thousands of millions of years to the universe.

But there is room for a good deal of doubt as to whether these huge speeds are real or not. They have not been obtained by any direct process of measurement, but are deduced by an application of what is known as Doppler's principle. It is a matter of common observation that the noise emitted by a motor car horn sounds deeper in pitch when it is receding from us than when it is coming towards us. On the same principle the light emitted by a receding body appears redder in colour than that emitted by a body approaching us, colour in light corresponding to pitch in sound. By accurately measuring the colour of well-defined spectral lines, the astronomer is able to discover whether the body emitting them is approaching us or receding from us, and can estimate the speed of the motion. And the only reason for thinking that the distant nebulæ are receding from us is that the light we receive from them appears redder than it ought normally to be.

Yet other things than speed are capable of reddening light; for instance, sunlight is reddened by the mere weight of the sun, it is reddened still more by the pressure of the sun's atmosphere; it is further reddened, although in a different way, in its passage through the earth's atmosphere, as we see at sunrise or sunset. The light emitted by certain stars of a different kind is reddened in a mysterious way we do not yet understand. Furthermore, on de Sitter's theory of the universe, distance alone produces a reddening of light, so that even if the distant nebulæ were standing still in space, their light would appear unduly red, and we should be tempted to infer that they were receding from us. None of these causes seems capable of explaining the observed reddening of nebular light, but quite recently Dr. Zwicky, of the California Institute, has suggested that still another cause of reddening may be found in the gravitational pull of stars and nebulæ on light passing near them—the same pull as causes the observed bending of starlight at an eclipse of the sun. Compton's experiments (p. 25) show that radiation is both deflected and red-

dened when it encounters electrons in space. When radiation interacts gravitationally with stars or other matter in space, it is known to be deflected, and Zwicky's suggestion is that it is reddened as well.

To test this suggestion, ten Bruggencate has examined the light from a number of globular clusters, all at about equal distances from us, but so selected that the amount of intervening gravitational matter varied greatly. The light from these showed a reddening, and if this were caused by the expansion of space, it ought to have been the same for all the clusters. Actually it proved to be far from uniform; it was much more nearly proportional to the amount of intervening matter, exactly as required by Zwicky's theory, and its actual amount agreed well enough with that predicted by the theoretical formula. As we can hardly imagine that the globular clusters, which belong to our own galactic system of stars, can be systematically running away from us, the case for supposing that the spiral nebulæ are running away becomes very much weaker, Zwicky's theory providing a possible explanation of the observed reddening of the light.

Other lines of evidence also suggest that the suspected recessions of the nebulæ may be spurious. For instance, the light from the nearest nebulæ is not redder but bluer than normal, and as light can only be made bluer by an actual physical approach, this can only mean that the nearest nebulæ are actually coming towards us. Moreover, the apparent speeds of the nebulæ are by no means strictly proportional to their distances; for instance, nebulæ believed to be at the same distance of seven million light years show deviations averaging 240 miles a second out of total speeds of 640 miles a second.

Nevertheless, if the universe is built in the way we have described, the nebulæ as a whole must undoubtedly be running away from us; theoretical considerations demand this and cannot be satisfied with anything less, but they do not tell us the speeds of the nebular motions. The work of Zwicky and ten Bruggencate in no way throws doubt on there being a real motion of recession; what it lays open to doubt is whether this motion is the same as astronomers have deduced from the reddening of the spectral lines. Possibly most of this reddening may be attributed to the effect suggested by Zwicky, or to some similar cause, while only a small residual represents a real

motion of recession. It is impossible to determine the speed of this motion because the smaller effect is entirely masked by the greater.

The question is still an open one, but if once it is accepted that the greater part of the apparent velocities of recession may be treated as spurious, the argument in favour of short lives for the stars disappears, and we become free to assign to them the long lives of millions of millions of years which the general evidence of astronomy seems to demand.

As we have already seen, this general evidence suggests that the sun has been pouring away mass in the form of radiation at a rate of 250 million tons a minute for a period of some millions of millions of years. Detailed calculation shows that the new-born sun must have had many times the mass of the present sun, in conformity with the general fact of observation that young stars are many times more massive than old stars. In what form could it store all the mass which has since disappeared in the form of radiation?

The rest-mass of an electron or other charged particle is generally enormously greater than its energy-mass, the latter assuming its greatest importance at high temperatures. Now the temperature at the centre of the sun is about 50 million degrees, and even here the rest-mass accounts for all but about one part in 200,000 of the total mass. It is improbable that the new-born sun can have been much hotter than this, so that it seems likely that the greater part of the mass of the primeval sun also must have resided in its rest-mass. If so, there is only one conclusion possible: the primeval sun must have contained many more electrons and protons, and therefore many more atoms, than now. These atoms can only have disappeared in one way: they must have been annihilated, and their mass must be represented by the mass of the radiation which the sun has emitted in its long life of millions of millions of years.

This argument may be thought somewhat precarious, because it deals with concepts so far out of the range of laboratory physics. Fortunately laboratory physics has quite recently obtained evidence, which, although far from being absolutely conclusive, provides valuable confirmation that this annihilation of matter is actually taking place on a vast scale out in the depths of space.

We could hardly expect to obtain direct evidence of the annihila-

tion of matter going on in stellar interiors, because the radiation produced in the process could only travel a very short distance before being absorbed by the substance of the star. This would be heated up, and the corresponding energy would ultimately be emitted by the star in the form of quite ordinary light and heat.

A mathematical analysis of the facts of astronomy suggests that the process of atomic annihilation would probably be spontaneous in the same way in which radio-active disintegration is spontaneous. If so, it would not be limited to the hot interiors of stars, but ought to be in progress wherever astronomical matter exists in sufficient abundance.

In its simplest form the process would consist of the simultaneous annihilation of a single electron and a single proton. We can picture it vividly if we think of these two charged particles rushing together under their mutual attraction with ever-increasing speed, until finally they coalesce; their electric charges then neutralize one another, and their combined energy is set free in a single flash of radiation—a "photon" of the kind discussed on page 24.

We have already seen (p. 36) how mass is "conserved" when an atom emits radiation. The atom parts with a certain amount of its mass, but this is not destroyed; it is carried away by the photon, and figures as the mass of the photon. If a proton and electron annihilate one another, the resulting photon must have a mass equal to the combined masses of the proton and electron which have disappeared. Now the combined mass of a proton and electron is known with great accuracy, for it is exactly equal to the mass of the hydrogen atom. Thus if the annihilation of matter really occurs, photons of mass exactly equal to that of the hydrogen atom ought to be traversing space in great numbers, and some of these ought to fall on the earth.

There may be even more massive photons than this, for we can imagine any kind of atom being suddenly annihilated, and setting loose its whole energy as a photon, whose mass would then be equal to that of the whole atom. One possibility is of special interest. Although we believe that all matter is in the last resort built up of protons and electrons, there is a peculiarly compact structure of four protons and two electrons which may almost be considered as a new

and independent unit. It is conspicuous in the radiation emitted by radio-active substances, and is commonly known as an α-particle. The helium atom, which is the next simplest atom after hydrogen, consists of an α-particle with two electrons revolving in orbital motion about it. As an α-particle has the same electric charge as two protons, it might undergo annihilation by coalescing with two electrons, in which event the resulting photon would have the same mass as a helium atom.

Photons of either of these two kinds would have an incomparably greater mass than the photons of any ordinary kind of radiation, and so ought to be immediately recognizable. Photons may be regarded as bullets, all travelling with a uniform speed—the speed of light. If a number of bullets are discharged from a gun with equal speeds, the more massive projectiles will have the greater capacity for doing damage, and so will have the greater penetrating power. It is the same with a mixed crowd of photons; the more massive photons have the greater penetrating power. There is a mathematical formula which enables us to deduce the penetrating power of a photon from its mass, and it shows that photons having the mass of atoms of either hydrogen or helium ought to have terrific powers of penetration.

We have already spoken of the highly penetrating radiation, commonly called "cosmic radiation," which falls on the earth from outer space, and is able to penetrate several yards of lead. For a long time it was not altogether clear whether this was a true radiation, or consisted of streams of electrons. The former alternative always seemed by far the more probable, because electrons would have to move with almost unthinkably high energy to force their way through many yards of lead before being brought to rest.

The matter now appears to be settled. A shower of electrons, falling on to the earth from outer space, would become entangled in the earth's magnetic field, and this would influence its motion. If the electrons were moving fast enough to have the observed penetrating power of cosmic radiation, calculation shows that almost the whole stream would be deflected from its course, and strike the earth near to one or other of its magnetic poles. No such preference is shown by the cosmic rays; different observers, working at different parts of the earth's surface, find that the radiation has the same

intensity everywhere. For instance, the British Australian and New Zealand Antarctic Expedition found the same intensity within 250 miles of the south magnetic pole as other observers had found in regions remote from the poles. This makes it reasonably certain that the "cosmic radiation" is true radiation, and not merely a shower of electrons. This being so, we can deduce the mass of the photons of the radiation from their observed penetrating power by the use of the formula already mentioned.

The penetrating power of this radiation has been studied with extreme care and skill by Professor Millikan and his colleagues at Pasadena, by Professor Regener of Stuttgart, and by many others. They all find that the radiation is a mixture of a number of constituents of very different penetrating powers, or, what is the same thing, a mixture of photons of different masses. Now it seems highly significant that the two ingredients of highest penetrating power consist of photons whose masses are, as nearly as we can tell, equal to the masses of the helium atom and the hydrogen atom respectively; in other words they are just the type of photons we should expect to find if, somewhere out in the far depths of space, protons and α-particles were being annihilated, the former in conjunction with the single electrons needed to neutralize their charges, and the latter in conjunction with the pairs of electrons needed for the same purpose.

It must be explained that the masses of the photons cannot be measured with absolute precision, so that it cannot be claimed with certainty that they are absolutely and precisely those to be expected from the annihilation in question. Yet the agreement is about as good as observation permits; in each case there is agreement to within about 5 per cent, and the penetrating power of the radiation can hardly be measured more closely than this. Such an agreement is too good to be dismissed as a mere coincidence, so that it seems highly probable that this radiation has its origin in the actual annihilation of protons and electrons.

Nevertheless, the matter is not yet beyond controversy, and the view I have just stated is not universally accepted by physicists. Professor Millikan, in particular, has suggested that cosmic radiation may originate in the process of building up heavy atoms out of

simpler light atoms, and so interprets it as evidence that "the creator is still on the job." To take the simplest illustration, a helium atom contains exactly the same ingredients as four hydrogen atoms—namely, four electrons and four protons—but its mass is only equal to that of 3·97 hydrogen atoms. Thus if four hydrogen atoms could somehow be hammered together to form a helium atom, the superfluous mass, that of 0·03 hydrogen atoms, would take the form of radiation, and a photon with 3 per cent of the mass of the hydrogen atom might be discharged. We cannot say it would be discharged, because if ever four hydrogen atoms fall together to form a helium atom, it seems likely that the process would occur in several stages, and so would result in the emission of a number of small photons rather than of one big one. Yet even if the whole of the liberated energy were to form one big photon, this would have less penetrating power than the actual cosmic radiation. If, however, 129 atoms of hydrogen were to fall together and form a single atom of xenon by one huge cataclysmic disturbance, the single photon emitted in the process would have about the same mass as the hydrogen atom, and so would have something like the same penetrating power as the second most penetrating constituent of actual cosmic radiation. On this view of the origin of the radiation, the less penetrating constituents can be very readily and naturally explained as originating out of the synthesis of atoms less complex than xenon. On the other hand, the most penetrating constituent of all seems to present a quite insuperable difficulty. If its photons originate out of the hammering together of hydrogen atoms to form a single huge atom, this atom must needs have an atomic weight in the neighbourhood of 500, which seems beyond the bounds of probability. It seems almost equally improbable that the second most penetrating constituent should be produced by the synthesis of atoms of xenon or other element of similar atomic weight, since all such atoms are of extreme rarity. Whatever the origin of the less penetrating constituents, the two most penetrating constituents can hardly, I think, be attributed with much plausibility to any other source than annihilation of matter.

The amount of this radiation which falls on the earth is tremendous. Millikan and Cameron have estimated it at about a tenth of

the total radiation received from all the stars in the sky, the sun of course excepted. Out in the depths of space, beyond the Milky Way, the highly penetrating radiation must still be about as plentiful as it is at the earth's surface, but starlight is far less plentiful, so that, on taking an average through space as a whole, this highly penetrating radiation is probably the commonest kind of radiation.

Its vast amount is explained in part by its high penetrating power, which almost endows it with immortality. An average beam of the radiation travelling through space for millions of millions of years will not encounter matter to absorb it to any appreciable extent. Thus we must think of space as being drenched with almost all the cosmic radiation which has ever been generated since the world began. Its rays come to us as messengers not only from the farthest depths of space, but also from the farthest depths of time. And, if we read it aright, their message seems to be that somewhere, sometime, in the history of the universe, matter has been annihilated, and this not in tiny, but in stupendous amounts.

If we accept the astronomical evidence of the ages of the stars and the physical evidence of the highly penetrating radiation as jointly establishing that matter can really be annihilated, or rather transformed into radiation, then this transformation becomes one of the fundamental processes of the universe. The conservation of matter disappears entirely from science, while the conservation of mass and of energy become identical. Thus the three major conservation laws, those of the conservation of matter, mass and energy, reduce to one. One simple fundamental entity which may take many forms, matter and radiation in particular, is conserved through all changes; the sum total of this entity forms the whole activity of the universe, which does not change its total quantity. But it continually changes its quality, and this change of quality appears to be the main operation going on in the universe which forms our material home. The whole of the available evidence seems to me to indicate that the change is, with possible insignificant exceptions, for ever in the same direction—for ever solid matter melts into insubstantial radiation: for ever the tangible changes into the intangible.

These concepts have been discussed at some length because they obviously have a very special bearing on the fundamental structure

of the universe. In the last chapter we saw how the wave-mechanics reduced the whole universe to systems of waves. Electrons and protons consisted of waves of one kind; radiation of waves of a different kind. The discussion of the present chapter has suggested that matter and radiation may not constitute two distinct and non-interchangeable, forms of waves. The two may be interchangeable, one passing into the other as the chrysalis passes into the butterfly—to which, as we shall see below (p. 101), some scientists might think it necessary to add "and as we can imagine the butterfly to pass back into the chrysalis."

This does not of course mean that matter and radiation are the same thing. The transformation of matter into radiation still means something, although the concept now looks incomparably less revolutionary than it looked when first I advanced it twenty-six years ago. Even if we knew all the facts with certainty, which we do not, it would be difficult to express the situation accurately in non-technical language, but possibly we may come fairly near to the truth if we think of matter and radiation as two kinds of waves—a kind which goes round and round in circles, and a kind which travels in straight lines. The latter waves of course travel with the velocity of light, but those which constitute matter travel more slowly. It has even been suggested, by Mosharrafa and others, that this may express the whole difference between matter and radiation, matter being nothing but a sort of congealed radiation travelling at less than its normal speed. We have already seen (p. 28) how the wave length of a moving particle depends on its speed. The dependence is such that a particle travelling with the speed of light would have precisely the same wave length as a photon of equal mass. This remarkable fact, as well as others, goes a long way towards suggesting that radiation may ultimately prove to be merely matter moving with the speed of light, and matter to be radiation moving with a speed less than that of light. But science is a long way from this as yet.

To sum up the main results of this and the preceding chapter, the tendency of modern physics is to resolve the whole material universe into waves, and nothing but waves. These waves are of two kinds: bottled-up waves, which we call matter, and unbottled waves, which we call radiation or light. The process of annihilation of matter is

merely that of unbottling imprisoned wave-energy and setting it free to travel through space. These concepts reduce the whole universe to a world of radiation, potential or existent, and it no longer seems surprising that the fundamental particles of which matter is built should exhibit many of the properties of waves.

CHAPTER FOUR

RELATIVITY AND THE ETHER

WE HAVE SEEN how modern physics reduces the universe to systems of waves. If we find it hard to imagine waves unless they travel through something concrete, let us say waves in an ether or ethers. I believe it was the late Lord Salisbury who defined the ether as the nominative of the verb "to undulate." If this definition will serve for the moment, we can have our ether without committing ourselves very far as to its nature. And this makes it possible to sum up the tendency of modern physics very concisely: modern physics is pushing the whole universe into one or more ethers. It will be well, then, to scrutinize the physical properties of these ethers with some care, since in them the true nature of the universe must be hidden.

It may be well to state our conclusion in advance. It is, in brief, that the ethers and their undulations, the waves which form the universe, are in all probability fictitious. This is not to say that they have no existence at all: they exist in our minds, or we should not be discussing them; and something must exist outside our minds to put this or any other concept into our minds. To this something we may temporarily assign the name "reality," and it is this reality which it is the object of science to study. But we shall find that this reality is something very different from what the scientist of fifty years ago meant by ether, undulations and waves, so much so that, judged by his standards and speaking his language for a moment, the ethers and their waves are not realities at all. And yet they are the most real things of which we have any knowledge or experience, and so are as real as anything possibly can be for us.

The concept of an ether entered science some two centuries ago or more. When the known properties of gross matter failed to explain a phenomenon, scientists met the difficulty by creating a hypothetical all-pervading ether, to which they attributed exactly the properties necessary to provide an explanation. There was of course a special temptation to resort to this procedure in problems which appeared to call for "action-at-a-distance." It is, on the face of it, such good

sound sense to assert that matter can only act where it is, and cannot possibly act where it is not, that he who argues to the contrary can hardly hope to carry the majority of his fellows with him. Descartes had gone so far as to argue that the bare existence of bodies separated by distance was a sufficient proof of the existence of a medium between them.

Thus when no gross material was present to transmit a mechanical action, such as that exerted by a magnet on a steel bar, or by the earth on a falling apple, the temptation to invoke an all-pervading ether became well-nigh irresistible, and what may be called the ether-habit invaded science. So that, as Maxwell expressed it: "Ethers were invented for the planets to swim in, to constitute electric atmospheres and magnetic effluvia, to convey sensations from one part of our body to another, till all space was filled several times over with ether." In the end there were almost as many ethers as unsolved problems in physics.

Fifty years ago only one of these ethers survived in serious scientific thought—the luminiferous ether, which was supposed to transmit radiation. The properties it needed to fulfil this function had been defined with ever-increasing precision by Huyghens, Thomas Young, Faraday and Maxwell. It was thought of as a jelly-like sea through which waves could travel, just as vibrations or undulations travel through a jelly. These waves were radiation which, as we now know, can take any one of the many forms of light, heat, infra-red or ultra-violet radiation, electromagnetic waves, X-rays, γ-rays and cosmic radiation.

The astronomical phenomenon of the "aberration of light," as well as a number of others, show that, if such an ether exists, the earth and all other moving bodies must pass through it without disturbing it. Or, if we take our position on the earth and study the phenomena from that standpoint, the ether must pass through the interstices of the earth and other solid bodies without hindrance—"like the wind through a grove of trees," to borrow the famous but inadequate simile of Thomas Young. It is inadequate because wind does in actual fact affect trees; the motions of their leaves, twigs and branches give some indication of its strength. But it can be shown that motion through the ether cannot in the least degree disturb solid

bodies which are at rest on the earth, or affect their motions if they are moving; we need not add ether-resistance to air-resistance in discussing what prevents our motor car making better speed.

Thus, if an ether exists, it is all the same whether the ether-wind is blowing past us at one mile an hour or a thousand miles an hour. This is in accordance with a dynamical principle which Newton had enunciated in his *Principia* :—

COROLLARY V: The motions of bodies included in a given space are the same among themselves, whether that space is at rest, or moves uniformly forwards in a right line without any circular motion.

Newton continues :—

A clear proof of which we have from the experiment of a ship, where all motions happen after the same manner whether the ship is at rest, or is carried uniformly forward in a right line.

This general principle shows that no experiment performed on board ship and confined to the ship alone can ever reveal the ship's velocity through a still sea. Indeed it is a matter of common observation that in calm weather we cannot even tell in which direction a ship is moving without looking at the sea.

If the ether-wind had affected terrestrial bodies, the disturbance it created would have given an indication of the speed with which it was blowing, just as the motions of the twigs of trees give an indication of ordinary wind-velocity. As things are, it is necessary to resort to other methods.

Although an ocean traveller cannot determine the speed of his ship by any observation which is confined to the ship, he can easily do so if he is free to observe the sea as well. If he drops a line and sounding-lead into the sea, a circular ripple will spread out; but every sailor knows that the point at which the line enters the water will not remain at the centre of this circle. The centre of the circle stays fixed in the water, but the point of entry of the line is dragged forward by the motion of the ship, so that the rate at which the point of entry advances from the centre of the circle will disclose the speed of the ship through the sea.

If the earth is ploughing its way through a sea of ether, an experiment conceived on similar lines ought to reveal the speed of its progress. The famous Michelson-Morley experiment was designed to

precisely this end. Our earth was the ship, and the physical laboratory of the University of Cleveland (Ohio) was the point of entry of the lead into the sea. The dropping of the lead was represented by the emission of a light-signal, and it was supposed that the light-waves which constituted this signal would make ripples on the sea of ether.

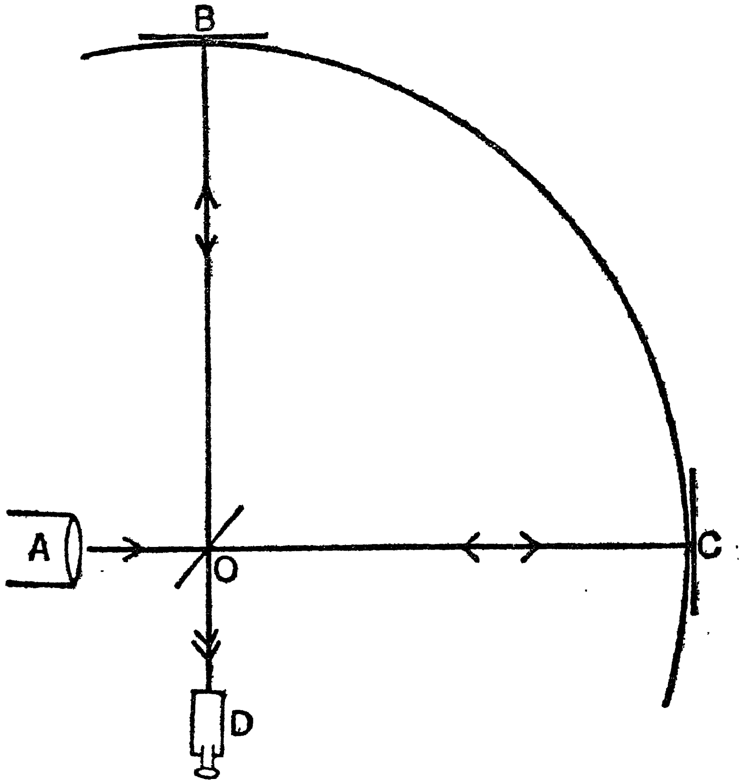

FIG. 1. Diagram to illustrate the Michelson-Morley experiment.

Light from a source *A* is projected on to a half-silvered mirror *O*, so that half is reflected along *OB* and the rest continues along *OC*, of length equal to *OB*, actually about 12 yards. Mirrors at *B* and *C* reflect the light back to *O*, and half of each beam then passes into a small telescope *D*. The amount by which one lags behind the other is compared with the lag when the whole apparatus has been turned through 90°. This procedure eliminates any error caused by *OB* and *OC* being slightly different in length.

The progress of the ripples could not be followed directly, but sufficient information could be obtained by arranging for mirrors to reflect the signal back to the starting-point. This made it possible to determine in effect the time which the light took to perform the double journey to and fro. If the earth were standing still in the ether, the time of a double journey of given length would of course always be the same, regardless of its direction in space. But if the earth were moving through a sea of ether in an easterly direction, it is easy to see that a double journey, first from east to west and then from west to east, ought to take slightly more time than one of equal length in north-south and south-north directions. No more recondite principle is involved than in the common experience that it takes longer to row a boat 100 yards up-stream and 100 yards down-stream than to row 200 yards across the stream; in the former case we go slowly up-stream, and come quickly down-stream, but the gain of time in rowing down with the current is not sufficient to make good the time previously lost in rowing up against the current. If two oarsmen of equal speed set out simultaneously to row the two courses, the cross-stream rower will arrive first, and the difference between their times of arrival will disclose the speed of the current. It was anticipated that, in precisely the same way, the difference in the times taken by the two beams of light in the Michelson-Morley experiment would disclose the speed of the earth's motion through the ether.

The experiment was performed many times, but no time-difference at all could be detected. Thus, on the hypothesis that our earth was surrounded by a sea of ether, the experiments seemed to show that its speed of motion through this sea of ether was zero. To all appearances, the earth stood permanently at rest in the ether, while the sun and the whole of creation circled round it; the experiments seemed to bring back the geocentric universe of pre-Copernican days. Yet it was impossible that this should be their true interpretation, for the earth was known to be moving round the sun at a speed of nearly twenty miles a second, and the experiments were sensitive enough to detect a speed of one-hundredth part of this.

Fitzgerald in 1893 and Lorentz independently in 1895 suggested an alternative interpretation. The experimenters had in effect tried to

make two rays of light travel simultaneously to and fro over two courses of equal length. Without losing anything of the essence of the experiment, we may imagine that the lengths of the two courses had been measured or compared by ordinary measuring rods—foot-rules, if we like. How was it known, Fitzgerald and Lorentz asked, that these rods, or the course laid out by them, retained their exact length while they were moving forward through a sea of ether? When a ship moves through the ocean, the pressure of the sea on its bows causes it to contract its length; it is, so to speak, squeezed up a little bit—a minute fraction of an inch—between the sea trying to hold its bows back and its screw trying to push its stern forward. In the same way a motor car moving through the air contracts as it is squeezed between the backward pressure of the wind on its wind-screen, and the forward drive of its rear wheels. If the apparatus used by Michelson and Morley contracted in the same way, the up-and-down stream course would always be shorter than the cross-stream course. This reduction of length would do something to compensate for the other disadvantages of the up-and-down stream course. A contraction of exactly the right amount would compensate for them completely, so that this and the cross-stream course would require precisely equal times. In this way, Fitzgerald and Lorentz suggested, it might be possible to account for the *nul* result of the experiment.

The idea was not wholly fanciful or hypothetical, for Lorentz showed very shortly afterwards that the electro-dynamical theory then current demanded that just such a contraction should actually occur. Although the contraction was not altogether analogous to those of ships or motor cars, these give a good enough idea of the mechanism involved. Actually Lorentz showed that if matter were a purely electrical structure, consisting solely of electrically charged particles, motion through the ether would cause the particles to re-adjust their positions, and they would not come to relative rest again until the body had contracted by a certain calculable amount. And this amount proved to be precisely that needed to account for the *nul* result of the Michelson-Morley experiment.

This not only explained, fully and completely, why the Michelson-Morley experiment had failed, but it further showed that every material measuring rod would necessarily contract just sufficiently to

conceal the earth's motion through the ether, so that all similar experiments were doomed to failure in advance. But other types of measuring rods are known to science; beams of light, electric forces, and so on, can be made to span the distances from point to point, and so provide the means for measuring distances. It was thought that where material measuring rods had failed, optical and electrical measuring rods might succeed. The trial was made, repeatedly and in many forms—the names of the late Lord Rayleigh, of Brace and of Trouton are eminent in this connexion. And every time it failed. If the earth had a speed x through the ether, every apparatus that the wit of man could devise confused the measurement of x by adding a spurious speed exactly equal to $-x$, and so reiterating the apparent zero answer of the original Michelson-Morley experiment.

The upshot of many years' arduous experimenting was that the forces of nature seemed without exception to be parties to a perfectly organized conspiracy to conceal the earth's motion through the ether. This of course is the language of the layman, not of the man of science. The latter prefers to say that the laws of nature make it impossible to detect the earth's motion through the ether. The philosophical contents of the two statements are precisely identical. In the same way the unscientific inventor may exclaim in despair that the forces of nature are in a conspiracy to prevent his perpetual motion machine from working, while the scientist knows that the obstacle is a far more serious barrier than a conspiracy; it is a natural law. And so, again, the zealous but unenlightened social reformer and the ignorant politician are alike apt to see conspiracies of the deepest dye behind the operation of those economic laws which make it impossible to extract a quart out of a pint pot.

In 1905 Einstein propounded the supposed new law of nature in the form "Nature is such that it is impossible to determine absolute motion by any experiment whatever." It was the first formulation of the principle of relativity.

Oddly enough, it was a reversion to the thought and doctrine of Newton. In his *Principia,* Newton had written :—

> It is possible that in the remote regions of the fixed stars or perhaps far beyond them, there may be some body absolutely at rest, but impossible to know, from the positions of bodies to one another in our regions, whether

any of these do not keep the same position to that remote body. It follows that absolute rest cannot be determined from the position of bodies in our regions.

He had qualified this by adding :—

I have no regard in this place to a medium, if any such there is, that freely pervades the interstices between the parts of bodies.

In other words, Newton had realized that without an all-pervading ether, it would be impossible to determine the absolute speed of motion through space, and had also seen that such a medium would provide an unmoving standard by reference to which the motions of all bodies could be measured.

The two intervening centuries had seen science busily engaged in discussing the properties of this supposed medium, and now Einstein at one blow deprived it of its most important property of all, that of providing a standard of rest, by reference to which the true speed of any motion could be measured.

Einstein's principle can be stated in another way, which makes its significance stand out more clearly. Astronomy has so far failed to discover Newton's body absolutely at rest, "in the remote regions of the fixed stars, or perhaps far beyond them," so that rest and motion are still merely relative terms. A ship which is becalmed is at rest only in a relative sense—relative to the earth; but the earth is in motion relative to the sun, and the ship with it. If the earth were stayed in its course round the sun, the ship would become at rest relative to the sun, but both would still be moving through the surrounding stars. Check the sun's motion through the stars and there still remains the motion of the whole galactic system of stars relative to the remote nebulæ. And these remote nebulæ move towards or away from one another with speeds of hundreds of miles a second or more; by going farther into space we not only find no standard of absolute rest, but encounter greater and greater speeds of motion. Unless we have an all-pervading ether to guide us, we cannot even say what we mean by absolute rest, still less can we find it. Einstein's principle now tells us that, so far as all the observable phenomena of nature are concerned, we are free to define "absolute rest" in any way we please.

It is a sensational message. We have a perfect right to say, if we so choose, that this room is at rest, and nature will not say us nay. If the

earth has a speed of 1,000 miles a second through the ether, then we must suppose that the ether is blowing through this room "like the wind through a grove of trees," at 1,000 miles a second. And the principle of relativity assures us that all the phenomena of nature in this room are absolutely unaffected by this 1,000 miles-a-second wind, and would indeed be just the same if the wind blew at 100,000 miles a second—or indeed if there were no wind at all.

It is not surprising or even novel that all mechanical phenomena, which have nothing to do with the supposed ether, should be the same; we have seen how this was known to Newton. But if an ether really exists, it seems amazing that the phenomena of optics and of electricity should be the same whether the ether which propagates them is standing still or blowing past and through us at thousands of miles a second. It quite inevitably raises the questions as to whether the ether, whose blowing is supposed to cause the wind, has any existence, or is a mere fiction of our imagination. For we must always remember that the existence of the ether is only an hypothesis, introduced into science by physicists who, taking it for granted that everything must admit of a mechanical explanation, argued that there must be a mechanical medium to transmit waves of light, and all other electrical and magnetic phenomena.

To justify their belief, they had to show that a system of pushes, pulls and twists could be devised in the ether to transmit all the phenomena of nature through space and deliver them up at the far end exactly as they are observed—much as a system of bell-wires transmits mechanical force from a bell-pull to a bell. The requisite system of pushes, pulls and twists was found in time, but proved to be exceedingly complicated. Perhaps this was not surprising; the ether had not only to transmit the observed effects, but to conceal its own existence while so doing. It could hardly be a simple matter to arrange that one single mechanism should transmit precisely the same phenomena whether the experimenter sat at rest or dashed through the ether at 1,000 miles a second while conducting his experiments. And, in point of fact, the mechanism thus devised proved to be open to the fatal objection that it could only make the two sets of phenomena the same by postulating two distinct mechanisms in these two cases.

We can illustrate the objection by discussing a simple phenomenon in detail. According to this scheme of ethereal transmission, charging a body with electricity sets up a state of strain in the surrounding ether, just like forcing a foreign body into a sea of jelly. When two bodies both at rest in the ether are charged with similar electricity, they repel one another, and their repulsion is supposed to be transmitted through the pressures which this state of strain establishes in the ether.

Suppose, however, that the two charged bodies, instead of being at rest in the ether, are moving through it with precisely the same speed of, say 1,000 miles a second from east to west. As the bodies are still at rest relatively to one another, the principle of relativity shows that the observable phenomena will still be precisely the same as when they were both at absolute rest in the ether. But a quite different mechanism produces the phenomena in this second case. Part of the repulsion is still the result of a strained state of the ether, but not all. The remainder is due to magnetic forces, and these cannot be explained as pressures or tensions in the ether, but have to be attributed to a complicated system of cyclones or whirlwinds.

More complicated electromagnetic phenomena are in general produced by a combination of electric and magnetic forces, and the two kinds of mechanism enter in different proportions with different speeds of motion through the ether. Thus the attempt to find a mechanical explanation of these phenomena involves the need for two distinct mechanisms to produce identically the same phenomenon. It has yet to be shown that any conceivable ether can accommodate both these mechanisms. But even if this could be proved, such a duality in the mechanism required to produce a single observable phenomenon is so contrary to the usual workings of nature that we cannot but feel that we are on the wrong track. Newton's theory of gravitation would have had little chance of acceptance if it had postulated a dual mechanism to explain why an apple fell from a tree, adding that one operated in summer and the other in autumn.

Newton himself laid stress on the necessity for avoiding duplicate mechanisms of this kind. His *Principia* contains a set of "Rules of Reasoning in Philosophy," of which the first two read as follows :—

RULE I

We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.

RULE II

Therefore to the same natural effects we must, as far as possible, assign the same causes.

As to respiration in a man and in a beast; the descent of stones in Europe and America; the light of our culinary fire, and of the sun; the reflection of light in the earth, and in the planets.

There is, however, a stronger case than this against supposing the luminiferous ether to transmit radiation and electrical action.

We have seen how electricity, magnetism and light all seem to be in a conspiracy to prevent our detecting motion through the ether, but gravitation remains; this has always stood apart from the other phenomena of physics, and has seemed to be of an entirely different nature. Now the law of gravitation involves the idea of distance; it asserts that the gravitational forces between two bodies depend on their distance apart, and so are equal at equal distances. Thus, in theory at least, the law of gravitation provides a measuring rod for the measurement of distances.

An ether which transmits electrical action can hardly transmit gravitational action as well, since all the properties with which we can endow it are used up in accounting for its transmission of electric and magnetic forces. The measuring rod which the law of gravitation provides may therefore be expected to be immune from the Fitzgerald-Lorentz contraction, and with such a measuring rod at our disposal we ought to be able to measure the earth's velocity through space.

Let us examine the possibility in terms of the simplest possible concrete case. Let us idealize our earth, and think of it as a perfect globe. As every point on its surface is now at the same distance from its centre, the force of gravity will be the same at all. If this idealized earth is now set in motion through the ether with a speed of 1,000 miles a second, the ordinary Fitzgerald-Lorentz contraction would cause its diameter to shrink by about 600 feet in the direction of

motion, and as the points at the end of this contracted diameter are now nearer to the earth's centre than other points on the earth's surface, all movable objects on the earth's surface would tend to slide downhill to these two points.

Even if it existed, this particular effect would be too small to be observed on our actual earth, because the irregularities of mountains and valleys, which we have idealized out of existence, would easily conceal a 600-foot contraction. Yet other gravitational phenomena of a similar kind are large enough to admit of observation, in particular the motions of the perihelia of the planets. And these show that gravitation is, so to speak, in league with the other forces of nature to conceal motion through the ether; if material measuring rods experience the Fitzgerald-Lorentz contraction, then the measures of length provided by the law of gravitation do the same. Yet as gravitation cannot be transmitted through the ether, it is hard to see how the measuring rods of the law of gravitation can be subject to this contraction. We can only conclude that the Fitzgerald-Lorentz contraction does not occur at all, and this compels us to abandon the mechanical ether.

We are compelled to start afresh. Our difficulties have all arisen from our initial assumption that everything in nature, and waves of light in particular, admitted of mechanical explanation: we tried in brief to treat the universe as a huge machine. As this has led us into a wrong path, we must look for some other guiding principle.

A safer guide than the will-o'-the-wisp of mechanical explanations is provided by Willian of Occam's principle: "Entia non sunt multiplicanda præter necessitatem." (We must not assume the existence of any entity until we are compelled to do so.) Its philosophical content is identical with that of Newton's first rule of philosophical reasoning quoted above. It is purely destructive; it takes something away, in the present instance the assumption of a mechanical universe with an underlying ether transmitting mechanical action through "empty space," and provides nothing to put in its place.

The obvious way of filling the gap is to introduce the relativity principle: "Nature is such that it is impossible to determine absolute motion by any experiment whatever." At first sight this may seem strange matter with which to fill the void caused by the withdrawal

of the ether: the two hypotheses are of such different natures that it may seem incredible that the second should be able to fill the same hole as the first. Yet in actual fact one is almost exactly the antithesis of the other: the primary function of the ether was to provide a fixed frame of reference—all its other properties were ancillaries necessitated by our efforts to reconcile the observed scheme of nature with our preliminary assumption. In its essence, the theory of relativity merely implies the negation of this preliminary assumption, so that the two are exactly antithetical.

Just because this is so, the issue between them is clear cut, and the experiment is capable of deciding it. The verdict is quite unambiguous; we have seen how all experimental efforts to detect an ether have failed, and in so doing have added confirmation to the hypothesis of relativity. Every single experiment ever performed has, so far as we know, decided in favour of the relativity hypothesis.

In this way the hypothesis of a mechanical ether was dethroned, and the principle of relativity set to reign in its stead. The signal for the revolution was a short paper which Einstein published in June, 1905. And with its publication, the study of the inner workings of nature passed from the engineer-scientist to the mathematician.

Until this time, we had thought of space as something around us, and of time as something that flowed past us, or even through us. The two seemed to be in every way fundamentally different. We can retrace our steps in space, but never in time; we can move quickly, or slowly, or not at all, in space as we choose, but no one can regulate the rate of flow of time—it rolls on at the same even uncontrollable rate for all of us. Yet Einstein's first results, as interpreted by Minkowski four years later, involved the amazing conclusion that nature knew nothing of all this.

We have already seen how matter is electrical in structure, so that all physical phenomena are ultimately electrical. Minkowski showed that the theory of relativity required all electrical phenomena to be thought of as occurring, not in space and time separately, as had hitherto been thought, but in space and time welded together so thoroughly that it was impossible to detect any traces of a join, so thoroughly that the whole of the phenomena of nature were unable to divide the product into space and time separately.

When we weld together length and breadth, we get an area—let us say a cricket field. The different players divide it up into its two dimensions in different ways; the direction which is "forwards" for the bowler is "backwards" for the batsman and is left-to-right for the umpire. But the cricket ball knows nothing of these distinctions: it goes where it is hit, directed only by laws of nature which treat the area of the cricket field as an indivisible whole, length and breadth being welded into a single undifferentiated unit.

If we further weld together an area (such as a cricket field) of two dimensions, and height (of one dimension) we obtain a space of three dimensions. So long as we do this near the earth, we can always call on gravity to separate our space out into "height" and "area"; for instance, the direction of height is that direction in which it is hardest to throw a cricket ball a given distance. But out in space, nature provides no means of effecting this separation; her laws know nothing of our purely local concepts of horizontal and vertical, and treat space as consisting of three dimensions between which no differentiation is possible.

By a process of welding we have passed in imagination from one dimension to two, and again from two to three. It is harder to pass from three to four because we have no direct experience of a four-dimensional space. And the four-dimensional space which we particularly want to discuss is peculiarly difficult to imagine because one of its dimensions does not consist of ordinary space at all, but of time; to understand the theory of relativity, we are called on to imagine a four-dimensional space in which three dimensions of ordinary space are welded on to one dimension of time.

Let us confront our difficulties singly, by first imagining a two-dimensional space obtained by welding together one dimension of ordinary space, namely length, and one dimension of time. Fig. 2 may help us to understand the concept. It represents, in diagrammatic form, the running schedule of the Cornish Riviera Express, which leaves Paddington at 10.30 a.m. and reaches Plymouth, 226 miles distant, at 2.30 p.m. The horizontal line represents the 226 miles of track connecting the two stations, and the vertical line represents the interval of time from 10.30 a.m. to 2.30 p.m. on any day on which the train is running.

The thick line represents the progress of the train. For instance the point *P* on this line is opposite the time 12.0 noon, and above the distance 91½ miles from Paddington, indicating that the train has travelled 91½ miles by noon. On the other hand a point such as *Q* represents a spot somewhere near Exeter at noon; it does not lie on

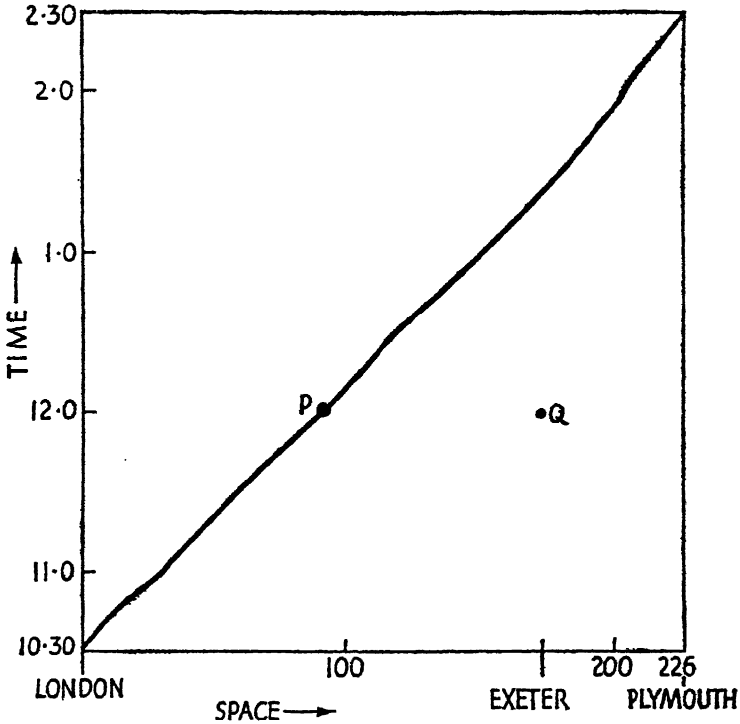

Fig. 2. Diagram to illustrate the motion of a train in space and time.

the thick line, because the train does not reach Exeter by noon. The whole area of the diagram represents all possible spots on the line between Paddington and Plymouth at all times between 10.30 a.m. and 2.30 p.m. Thus by welding together a length, namely 226 miles of track, and a time, namely four hours around midday, we have obtained an area having one dimension of space and one of time.

In the same way we can imagine the three dimensions of space and one dimension of time welded together, forming a four-dimensional volume which we shall describe as a "continuum." Then the principle of relativity, as interpreted by Minkowski, states that all the phenomena of electromagnetism may be thought of as occurring in a continuum of four dimensions—three dimensions of space and one of time—*in which it is impossible to separate the space from the time in any absolute manner*. In other words the continuum is one in which space and time are so completely welded together, so perfectly merged into one, that the laws of nature make no distinction between them, just as, on the cricket field, length and breadth are so perfectly merged into one that the flying cricket ball makes no distinction between them, treating the field merely as an area in which length and breadth separately have lost all meaning.

It may be objected that Fig. 2 gives no help towards imagining this continuum; that it is merely diagrammatic; that it does not really represent the welding together of true time and length, but merely of one length with another length, which as every one knows gives an area—in this case a page of the book. We need not linger over this objection because our final conclusion will be that the four-dimensional continuum is, in much the same sense, also purely diagrammatic. It merely provides a convenient framework in which to exhibit the workings of nature, just as Fig. 2 provides a convenient framework in which to exhibit the running of a train.

Yet, just because we can exhibit all nature within this framework, it must correspond to some sort of an objective reality. But its division into space and time is not objective; it is merely subjective. If you and I happen to be moving with different speeds, space and time mean something different to you from what they mean to me; we divide the continuum into space and time in different ways, just as, if we happen to be facing in different directions, "in front" and "to the left" have different meanings for the two of us, or just as the bowler and the batsman divide up a cricket field in different ways of which the cricket ball knows nothing. Even if I change my own speed of motion, by putting on the brakes of my car, or jumping on to a moving bus, I am re-arranging the division of the continuum into space and time for myself. And the essence of the theory of

relativity is that nature knows nothing of these divisions of the continuum into space and time; in Minkowski's words: "Space and time separately have vanished into the merest shadows, and only a sort of combination of the two preserves any reality."

This shows in a flash why the old luminiferous ether had inevitably to fade out of the picture—it claimed to fill "all space," and so to divide up the continuum objectively into time and space. And the laws of nature, not recognizing such divisions as a possibility, cannot recognize the existence of the ether as a possibility.

Thus if we want to visualize the propagation of light waves and electromagnetic forces by thinking of them as disturbances in an ether, our ether must be something very different from the mechanical ether of Maxwell and Faraday. It may be thought of as a four-dimensional structure, filling up the whole continuum, and so extending through all space and all time, in which case we can all enjoy the same ether. Or, if we want a three-dimensional ether, it must be subjective in a way in which the Maxwell-Faraday ether was not. Each of us must then carry his own ether about with him, much as in a shower of rain each observer carries his own rainbow about with him. If I change my speed of motion I create a new ether for myself, just as, if I step a few paces in a sunny shower, I acquire a new rainbow for myself. And unless the expanding universe described above (p. 42) is a pure illusion, every one's ether must incessantly expand and stretch. Whether a structure of this kind ought to be called an ether, is open to question; it would be hard to find any property it has in common with the old nineteenth-century ether. Indeed, as the hypothesis of relativity is the exact negation of the existence of the old ether, it is clear that any ether that relativity can allow to remain in being must be the exact opposite of the old ether. This being so, it seems a mistaken effort to call them by the same name.

I do not think there is any real divergence of opinion among competent scientists on all this. Sir Arthur Eddington truly says that about half the leading physicists assert that the ether exists and the other half deny its existence, but continues: "Both parties mean exactly the same thing, and are divided only by words." Sir Oliver Lodge, who has been the staunchest supporter of the objective existence of an ether in recent years, writes :—

The ether in its various forms of energy dominates modern physics, though many prefer to avoid the term "ether" because of its nineteenth-century associations, and use the term "space." The term used does not much matter.

Clearly, if it is a matter of indifference whether we speak of the ether or of space, of the existence or non-existence of the ether, then even its most ardent devotees cannot claim much objective reality for it. I think the best way of regarding the ether is as a frame of reference just as the diagram on page 67 is a frame of reference; its existence is just as real, and just as unreal, as that of the equator, or the north pole, or the meridian of Greenwich. It is a creation of thought, not of solid substance. We have seen how *the* ether, which is the same for all of us, as distinguished from your ether or my ether, must be supposed to pervade all time as well as all space, and that no valid distinction can be drawn between its occupancy of time and space. The framework in time to which we must compare the time-dimension of the ether is of course ready to hand—it is the division of the day into hours, minutes and seconds. And unless we think of this division as material, which no one ever does or has done, we are not justified in thinking of the ether as material. In the new light which the theory of relativity has cast over science, we see that a material ether filling space could only be accompanied by a material ether filling time—the two stand or fall together.

Thus we seem on fairly safe ground in thinking of the ether as a pure abstraction; it is at best "a local habitation and a name." Yet a local habitation for what? The universe consists only of waves, and we first introduced the ether as the nominative of the verb "to undulate." This conception must now be abandoned, for the utterly unsubstantial ether we are now considering is as incapable of undulation as is the equator or the meridian of Greenwich. It does not of course follow that nothing undulatory can be propagated through this immaterial medium. We speak of a heat wave, or a suicide wave, and do not ask for an undulating medium to convey them. The heat wave might be propagated round the equator, and the suicide wave along the meridian of Greenwich.

It may be thought that, although we can obtain no direct evidence of the existence of the ether, yet we can find evidence of something

of the nature of waves passing through it, in all the phenomena which are generally taken to prove the undulatory nature of light—Newton's rings, diffraction patterns, and interference phenomena in general. This, however, is not so, for again we have no knowledge of the supposed waves except where there are particles of matter to reveal them to us. The phenomena just mentioned give us no knowledge of things passing through the ether, but only of things falling on matter. So far as we know, nothing at all is propagated that is more concrete than a mathematical abstraction—it is like astronomical noon being propagated over the surface of the earth as the earth turns round under the sun. Yet I can imagine a physicist intervening with an objection at this stage; it would be something like this:—

Physicist. The sunshine out of doors represents energy which was generated in the sun. Eight minutes ago it was in the sun; now it is here. Consequently it must have come from the sun, and so must have travelled through the space which intervenes between the sun and us. It seems to me, then, that energy must be propagated through the space which intervenes between the sun and us. It seems to me, then, that energy must be propagated through space.

Mathematician. Let us make the question at issue as precise as possible. Let us fix our attention on a definite parcel of sunlight, say that which falls on my book in the space of a second, as I sit reading out in the bright sunshine. This, you say, was in the sun eight minutes ago. Four minutes ago it was, I suppose, out in space, halfway between the sun and ourselves. Two minutes ago it was three-quarters of the way towards us?

Physicist. Yes; and that is what I call being propagated through space, energy moves from one bit of space to another.

Mathematician. Your concept implies that at any instant the different little bits of space are occupied by different amounts of energy. If so, it ought of course to be possible to calculate or measure how much is in a given bit of space at a given instant. If you assume that the sun is at rest in an ether, and that sunlight is energy propagated through this ether, then, I admit, you can get a quite definite answer to the problem; Maxwell gave it in 1863. Also if you assume that the sun, and of course the whole solar system with it, is moving steadily through the ether at a known speed, say 1,000 miles a second, you

can also get a definite answer to your problem. But—and this is the crux of the matter—the two answers are different. Will you tell me which is the right one?

Physicist. Obviously the first is right if the sun is at rest in the ether, and the second if the sun has a steady speed of 1,000 miles a second through the ether.

Mathematician. Yes, but we are in agreement that "at rest in the ether" means nothing at all, and "a steady speed of 1,000 miles a second through the ether" means nothing at all. If we try to attach any meaning to them, all the phenomena of nature insist that the same meaning must be attached to both. Consequently I find your answer meaningless.

In some such way as this we find that the attempt to parcel out energy amongst the different parts of space leads to an ambiguity which cannot be resolved. It seems natural to suppose that our attempt is a misguided one, and that the partition of energy through space is illusory.

And again, the attempt to regard the flow of energy as a concrete stream always defeats itself. With a stream of water, we can say that a certain particle of water is now here, now there; with energy it is not so. The concept of energy flowing about through space is useful as a picture, but leads to absurdities and contradictions if we treat it as a reality. Professor Poynting gave a well-known formula which tells us how energy may be pictured as flowing in a certain way, but the picture is far too artificial to be treated as a reality; for instance, if an ordinary bar-magnet is electrified and left standing at rest, the formula pictures energy flowing endlessly round and round the magnet, rather like innumerable rings of children joining hands and dancing to all eternity round a maypole. The mathematician brings the whole problem back to reality by treating this flow of energy as a mere mathematical abstraction. Indeed he is almost compelled to go further and treat energy itself as a mere mathematical abstraction—the constant of integration in a differential equation. If he does this, it becomes no more absurd that there should be two different values for the amounts of energy in a given region of space than that there should be two different times at the same place, such as standard and daylight-saving times in New York, or civil and sidereal

times in an observatory. If he declines to do this, he is left to defend the untenable position that the universe is built, in a concrete way, of energy in its alternative forms of matter and radiation, and that energy cannot be localized in space. We shall discuss this situation further below (p. 98).

Before proceeding to consider other developments of the theory of relativity, it seems appropriate to discard the word "ether" in favour of the term "continuum," this meaning the four-dimensional "space" we have already imagined, in which the three dimensions of ordinary space are supplemented by time acting as a fourth dimension.

Laws of nature express happenings in time and space, and so can of course be stated with reference to this four-dimensional continuum. In discussing these laws quantitatively, it is found convenient to imagine both time and space measured in a very special and a very artificial manner. We shall not measure lengths in terms of feet or centimetres, but in terms of a unit of about 186,000 miles, which is the distance that light travels in a second. And we shall not measure time in ordinary seconds, but in terms of a mysterious unit equal to a second multiplied by $\sqrt{-1}$ (the square root of -1). Mathematicians speak of $\sqrt{-1}$ as an "imaginary" number, because it has no existence outside their imaginations, so that we are measuring time in a highly artificial manner. If we are asked why we adopt these weird methods of measurement, the answer is that they appear to be nature's own system of measurement; at any rate they enable us to express the results of the theory of relativity in the simplest possible form. If we are further asked why this is so, we can give no answer—if we could, we should see far deeper than we now do into the inner mysteries of nature.

Let us, then, agree to use the weird system of measurement just described, and construct our continuum accordingly. Minkowski showed that if the hypothesis of relativity is true, the statement of the laws of nature must show no distinction between time and space, when the continuum is constructed in the way just described; the three dimensions of space and one of time enter as absolutely equal partners into the formulation of every natural law. If they did not, the law would be at variance with the principle of relativity.

It was soon noticed that Newton's famous law of gravitation did not conform to the condition just stated, so that either Newton's law or the hypothesis of relativity was wrong. Einstein examined what alterations would have to be applied to Newton's law to bring it into conformity with the hypothesis of relativity, and found that the necessary changes involved the appearance of three new phenomena which were not implied in Newton's old law. In other words, nature provided three distinct ways of deciding observationally between the laws of Einstein and Newton. When the test was made, the decision was favourable to Einstein in every case.

What we call the "law of gravitation" is, strictly speaking, nothing more than a mathematical formula giving the acceleration of a moving body—the rate at which it changes its speed of motion. Newton's law lent itself to a rather obvious mechanical interpretation: a body moved in the same way as it would if it were "drawn off from its rectilinear motion" (to use Newton's phrase) by a force proportional to the inverse square of the distance. Newton accordingly supposed such a force to exist; it was called the "force of gravity." Einstein's law did not lend itself to any such interpretation in terms of forces, or indeed to any mechanical interpretation whatever—still another indication, if one were needed, that the age of mechanical science had passed. But it was found to admit of an easy interpretation in terms of geometry. The effect of a mass of gravitating matter was not, as Newton had imagined, to exude a "force," but to distort the four-dimensional continuum in its neighbourhood. The moving planet or cricket ball was no longer drawn off from its rectilinear motion by the pull of a force, but by a curvature of the continuum.

It is difficult enough to imagine the four-dimensional continuum even when undistorted, and still more so to imagine its distortions, but the two-dimensional analogy of an area may help. Surfaces such as a cricket field or the skin of our hand are two-dimensional continua; the analogies of the distortions produced by gravitating masses are mole hills or blisters. The cricket ball which rolls over a mole hill is "drawn off from its rectilinear motion" like a comet or a ray of light passing near the sun. And the combined distortions of the four-dimensional continuum produced by all the matter in the universe

cause the continuum to bend back on itself to form a closed surface so that space becomes "finite," with the results that have been already discussed in Chapter Two.

Space and time as separate entities have already disappeared from the universe; gravitational forces now disappear also, leaving nothing but a crumpled continuum. Nineteenth-century science had reduced the universe to a playground of forces of only two kinds—gravitational forces which govern the major phenomena of astronomy, besides keeping our bodies and possessions on the earth's surface, and electromagnetic forces, which control all other physical phenomena, such as light, heat, sound, cohesion, elasticity, chemical change, and so forth. Now that gravitational forces have disappeared from science, it is natural to wonder why electromagnetic forces happen to survive, and how they figure in the continuum. Although the question is not finally settled, it seems likely that these, too, are destined to go the way of gravitational forces. Weyl and Eddington successively propounded theories which dispensed with electromagnetic forces altogether, and tried to interpret all physical phenomena as consequences of the peculiar geometry of the continuum. Both these proved open to objections; the fate of a more recent theory of the same type by Einstein is still in the balance. But whatever theory finally prevails, it seems fairly certain that in some way or other electromagnetic forces will ere long be resolved merely into a new type of crumpling of the continuum, essentially different in its geometry, but in no other respect, from that whose effects we describe as gravitation. If so, the universe will have resolved itself into an empty four-dimensional space, totally devoid of substance, and totally featureless except for the crumplings, some large and some small, some intense and some feeble, in the configuration of the space itself.

What we have hitherto spoken of as the propagation of energy, such as the passage of sunlight from sun to earth, now reduces to nothing more than the continuity of a corrugated crumpling along a line in the continuum which extends over about eight minutes of our terrestrial time and about 92,500,000 miles of our terrestrial length. We now see that we cannot picture it as the propagation of anything concrete or objective through space unless we first

divide the continuum objectively into space and time, and this is precisely what we are forbidden to do.

To sum up, a soap bubble with irregularities and corrugations on its surface is perhaps the best representation, in terms of simple and familiar materials, of the new universe revealed to us by the theory of relativity. The universe is not the interior of the soap bubble but its surface, and we must always remember that, while the surface of the soap bubble has only two dimensions, the universe bubble has four—three dimensions of space and one of time. And the substance out of which this bubble is blown, the soap film, is empty space welded on to empty time.

CHAPTER FIVE

INTO THE DEEP WATERS

LET US STUDY in more detail this soap bubble, blown of emptiness, by which modern science portrays the universe. Its surface is richly marked with irregularities and corrugations. Two main kinds may be discerned, which we interpret as radiation and matter, the ingredients of which the universe appears to us to be built.

Markings of the first kind represent radiation. All radiation travels at the same uniform speed of about 186,000 miles a second. If the train in Fig. 2 (p. 67) had travelled at a uniform speed of a mile a minute, its motion would have been represented by a perfectly straight line inclined at an angle of 45° to the vertical. A succession of trains all moving uniformly at a mile a minute would be represented by a lot of lines all parallel to this. Now let us change our standard speed from a mile a minute to 186,000 miles a second, and replace the one direction from London to Plymouth by all the directions in space. The diagram on page 67 now becomes replaced by the four-dimensional continuum, and radiation is represented by a set of lines all making the same angle (45°) with the direction of time advancing.

Markings of the second kind represent matter. This moves through space at a variety of different speeds, but all are small in comparison with the speed of light. To a first rough approximation, we may regard all matter as standing still in space, and moving forward only in time, so that the markings which represent it run in the direction of time advancing, just as, if the train whose journey is shown in Fig. 2 (p. 67) were to stop at a station, its stay there would be represented by a bit of vertical line.

The markings which represent matter tend to form broad bands across the surface of the soap bubble, like broad streaks of paint on a canvas. This is because the matter of the universe tends to aggregate into large masses—stars and other astronomical bodies. These bands or streaks are known as "world lines"; the world line of the sun traces out the position of the sun in space which corresponds to each

instant of time. We can picture this diagrammatically in Fig. 3, below.

Just as a cable is formed of a great number of fine threads, so the world line of a large body like the sun is formed of innumerable smaller world lines, the world lines of the separate atoms of which

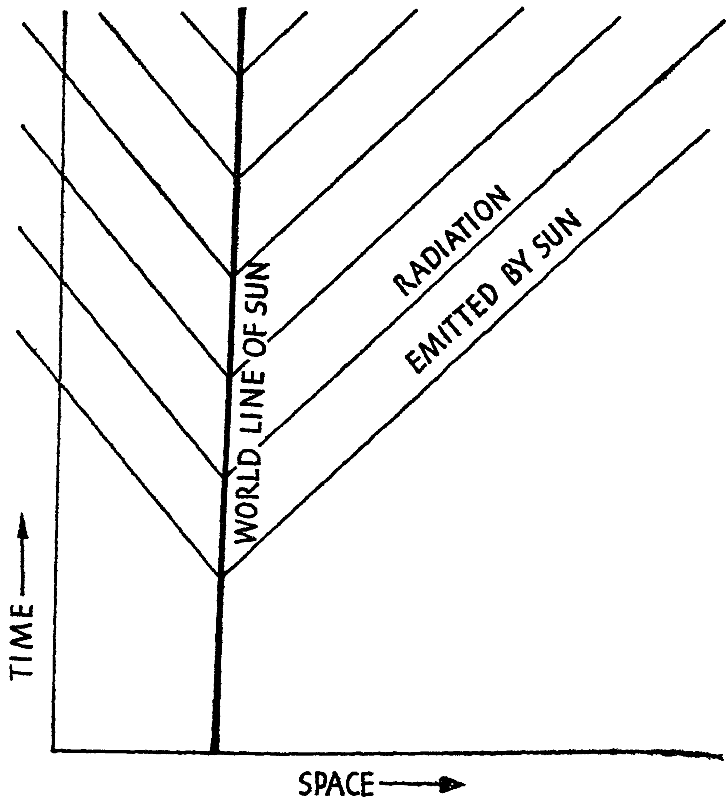

FIG. 3. Diagram to illustrate the motion of the sun and its radiation in space and time (cf. Fig. 2 on page 67).

the sun is composed. Here and there these fine threads enter or leave the main cable as an atom is swallowed up by, or ejected from, the sun.

We may think of the surface of the bubble as a tapestry whose threads are the world lines of atoms. In so far as atoms are permanent

and indestructible, the thread-like world lines of the atoms traverse the whole length of the picture in the direction of time advancing. But if atoms are annihilated, the threads may end abruptly and tassels of world lines of radiation spread out from their broken ends. As we move timewards along the tapestry, its various threads for ever shift about in space and so change their places relative to one another. The loom has been set so that they are compelled to do this according to definite rules which we call the "laws of nature."

The world line of the earth is a smaller cable, made up of several strands, these representing the mountains, trees, aeroplanes, human bodies and so on, the aggregate of which makes up the earth. Each strand is made up of many threads—the world lines of its atoms. A strand which represents a human body does not differ in any observable essentials from the other strands. It shifts about, relatively to the other strands, less freely than an aeroplane, but more freely than a tree. Like the tree, it begins as a small thing and increases by continual absorption of atoms from outside—its food. The atoms of which it is formed do not differ in essentials from other atoms; exactly similar atoms enter into the composition of mountains, aeroplanes and trees.

Yet the threads which represent the atoms of a human body have the special capacity of conveying impressions through our senses to our minds. These atoms affect our consciousness directly, while all the other atoms of the universe can only affect it indirectly, through the intermediary of these atoms. We can most simply interpret consciousness as something residing entirely outside the picture, and making contact with it only along the world lines of our bodies.

Your consciousness touches the picture only along your world line, mine along my world line, and so on. The effect produced by this contact is primarily one of the passage of time; we feel as if we were being dragged along our world line so as to experience the different points on it, which represent our states at the different instants of time, in turn.

It may be that time, from its beginning to the end of eternity, is spread before us in the picture, but we are in contact with only one instant, just as the bicycle-wheel is in contact with only one point of the road. Then, as Weyl puts it, events do not happen; we merely

come across them. Or, as Plato expressed it twenty-three centuries earlier in the *Timaeus*:—

> The past and future are created species of time which we unconsciously but wrongly transfer to the eternal essence. We say "was," "is," "will be," but the truth is that "is" can alone properly be used.

In this case, our consciousness is like that of a fly caught in a dusting-mop which is being drawn over the surface of the picture; the whole picture is there, but the fly can only experience the one instant of time with which it is in immediate contact, although it may remember a bit of the picture just behind it, and may even delude itself into imagining it is helping to paint those parts of the picture which lie in front of it.

Or again, it may be that our consciousness should be compared to the feeling in the finger of the painter as he guides the brush forward over the still unfinished picture. If so, the impression of influencing the parts of the picture yet to come is something more than a pure illusion. At present science can tell us very little as to the way in which our consciousness apprehends the picture; it is concerned mainly with the nature of the picture.

We have seen how the ether which was at one time supposed to fill the universe has been reduced to an abstraction, a framework of empty space, amounting to nothing more than the spatial dimensions of a soap bubble, whose soap-film consists of vacancy. The waves which were at one time supposed to traverse this ether have also been reduced to little more than an abstraction: they are corrugations on a cross-section of the bubble by time.

This quality of abstractness in what were at one time regarded as material "ether-waves" recurs in a far more acute form when we turn to the system of waves which make up an electron. The "ether" in terms of which we find it convenient to explain ordinary radiation —say, sunlight—has three dimensions of space, in addition to its one dimension of time. So also has the ether in which we describe the waves which constitute a single electron isolated in space; this may or may not be the same ether as before, but it is similar in having three dimensions of space and one of time. But a single electron isolated in space provides a perfectly eventless universe, the simplest conceivable event occurring when two electrons meet one another.

And to describe, in its simplest terms, what happens when two electrons meet one another, the wave-mechanics asks for a system of waves in an ether which has seven dimensions; six are of space, three for each of the electrons, and one is of time. To describe a meeting of three electrons, we need an ether of ten dimensions, nine of space (again three for each electron) and one of time. Were it not for the last dimension of time which binds all the others together, the various electrons would all exist in separate non-communicating three-dimensional spaces. Thus time figures as the mortar which binds the bricks of matter together, much as, on the spiritual plane, the "windowless monads" of Leibnitz were bound together by the universal mind. Or, perhaps with a nearer approach to actuality, we may think of the electrons as objects of thought, and time as the process of thinking.

Most physicists would, I think, agree that the seven-dimensional space in which the wave-mechanics pictures the meeting of two electrons is purely fictitious, in which case the waves which accompany the electrons must also be regarded as fictitious. Thus Professor Schrödinger, writing of the seven-dimensional space, says that although it

> has quite a definite physical meaning, it cannot very well be said to "exist"; hence a wave-motion in this space cannot be said to "exist" in the ordinary sense of the word either. It is merely an adequate mathematical description of what happens. It may be that also in the case of one single (electron), the wave-motion must not be taken to "exist" in *too* literal a sense, although the configuration-space happens to coincide with ordinary space in this particularly simple case.

Yet it is hard to see how we can attribute a lower degree of reality to the one set of waves than to the other: it is absurd to say that the waves of single electrons are real, while those of pairs of electrons are fictitious. And the waves of single electrons are real enough to record themselves on a photographic plate and produce the patterns shown in *Frontispiece* Plate II. We can only regain complete consistency by supposing all the waves, those of two electrons, those of one electron, and the waves on Professor Thomson's photographic plate, to have the same degree of reality or unreality.

Some physicists meet this situation by regarding the electron-

waves as waves of probability. When we speak of a tidal-wave we mean a material wave of water which wets everything in its path. When we speak of a heat-wave we mean something which, although not material, warms up everything in its path. But when the evening papers speak of a suicide-wave, they do not mean that each person in the path of the wave will commit suicide; they merely mean that the likelihood of his doing so is increased. If a suicide-wave passes over London, the death-rate from suicide goes up; if it passes over Robinson Crusoe's Island, the probability that the sole inhabitant will kill himself goes up. The waves which represent an electron in the wave-mechanics may, it is suggested, be probability-waves, whose intensity at any point measures the probability of the electron being at that point.

Thus at each point on Professor Thomson's plate (Figs. 2 and 3, *Frontispiece* Plate II), the wave-intensity measures the probability that a single diffracted electron would hit the plate at that spot. When a whole crowd of electrons is diffracted, the total number which hit any spot is, of course, proportional to the probability of each individual hitting the spot, so that the darkening of the plate gives a measure of the probability per electron.

This view has the great merit that it enables the electrons to preserve their identity. If the electron-waves were true material waves, each system of waves would probably be dispersed by the experiment, so that no electrified particles would survive as such in the diffracted beam. Indeed, any encounter with matter would break up electrons, which could not be regarded as permanent structures. Actually, of course, it is the shower of electrons, rather than the individual, that is diffracted; the individual electrons move as particles and retain their identity as such.

All this is in accordance with Heisenberg's "uncertainty principle" (p. 17), which makes it impossible ever to say: "An electron is here, at this precise spot, and is moving at just so many miles an hour"; it is also in accordance with the general principle of Dirac, which has already been explained (p. 19). Yet these two principles alone are not enough to specify the full nature of the electron-waves.

Heisenberg and Bohr have suggested that these waves must be regarded merely as a sort of symbolic representation of our know-

ledge as to the probable state and position of an electron. If so, they change as our knowledge changes, and so become largely subjective. Thus we need hardly think of the waves as being located in space and time at all; they are mere visualizations of a mathematical formula of an undulatory, but wholly abstract, nature.

A still more drastic possibility, again arising out of a suggestion made by Bohr, is that the minutest phenomena of nature do not admit of representation in the space-time framework at all. On this view the four-dimensional continuum of the theory of relativity is adequate only for some of the phenomena of nature, these including large-scale phenomena and radiation in free space; other phenomena can only be represented by going outside the continuum. We have, for instance, already tentatively pictured consciousness as something outside the continuum, and have seen how the meeting of two electrons can most simply be pictured in seven dimensions. It is conceivable that happenings entirely outside the continuum determine what we describe as the "course of events" inside the continuum, and that the apparent indeterminacy of nature may arise merely from our trying to force happenings which occur in many dimensions into a smaller number of dimensions. Imagine, for instance, a race of blind worms, whose perceptions were limited to the two-dimensional surface of the earth. Now and then spots of the earth would sporadically become wet. We, whose faculties range through three dimensions of space, call the phenomenon a rain-shower, and know that events in the third dimension of space determine, absolutely and uniquely, which spots shall become wet and which shall remain dry. But if the worms, unconscious even of the existence of the third dimension of space, tried to thrust all nature into their two-dimensional framework, they would be unable to discover any determinism in the distribution of wet and dry spots; the worm-scientists would only be able to discuss the wetness and dryness of minute areas in terms of probabilities, which they would be tempted to treat as ultimate truth. Although the time is not yet ripe for a decision, this seems to me, personally, the most promising interpretation of the situation. Just as the shadows on a wall form the projection of a three-dimensional reality into two dimensions, so the phenomena of the space-time continuum may be four-dimensional projections of

realities which occupy more than four dimensions, so that events in time and space become

> no other than a moving row
> of Magic Shadow-shapes that come and go.

It may perhaps be objected that we have paid altogether too much attention to the wave-mechanics, which after all is only a mathematical picture, when probably innumerable other mathematical pictures might serve equally well, and might lead to entirely different conclusions.

It is true that the wave-mechanics picture can make no claim to uniqueness. Other systems are in the field, particularly those of Heisenberg and Dirac. Yet in the main these only say the same thing in other, and frequently more complicated, words. No other system yet devised explains things so simply, or seems to be so true to nature, as the wave-mechanics of de Broglie and Schrödinger. Photographs such as those shown in *Frontispiece* Plate II bear witness that waves of definite wave length are somehow fundamental in nature's scheme; these waves form the fundamental concept of the wave-mechanics, but only appear as rather far-fetched by-products in the other systems. Also, just because of its inherent simplicity, the wave-mechanics has shown a capacity for penetrating much further into the secrets of nature than any other system, so that other systems are already falling somewhat into the background. To vary our metaphor, they have served a valuable purpose as scaffolding, but there seems to be but little inclination to add to them further.

If then we are to concentrate on one picture, we seem justified in selecting that provided by the wave-mechanics, although in point of fact either the system of Heisenberg or that of Dirac would lead us to very much the same conclusion. The essential fact is simply that *all* the pictures which science now draws of nature, and which alone seem capable of according with observational fact, are *mathematical* pictures.

Most scientists would agree that they are nothing more than pictures—fictions if you like, if by fiction you mean that science is not yet in contact with ultimate reality. Many would hold that, from the broad philosophical standpoint, the outstanding achievement of

twentieth-century physics is not the theory of relativity with its welding together of space and time, or the theory of quanta with its present apparent negation of the laws of causation, or the dissection of the atom with the resultant discovery that things are not what they seem; it is the general recognition that we are not yet in contact with ultimate reality. To speak in terms of Plato's well-known simile, we are still imprisoned in our cave, with our backs to the light, and can only watch the shadows on the wall. At present the only task immediately before science is to study these shadows, to classify them and explain them in the simplest possible way. And what we are finding, in a whole torrent of surprising new knowledge, is that the way which explains them more clearly, more fully and more naturally than any other is the mathematical way, the explanation in terms of mathematical concepts. It is true, in a sense somewhat different from that intended by Galileo, that "Nature's great book is written in mathematical language." So true is it that no one except a mathematician need ever hope fully to understand those branches of science which try to unravel the fundamental nature of the universe—the theory of relativity, the theory of quanta and the wave-mechanics.

The shadows which reality throws on to the wall of our cave might *a priori* have been of many kinds. They might conceivably have been perfectly meaningless to us, as meaningless as a cinematograph film showing the growth of microscopic tissues would be to a dog who had strayed into a lecture-room by mistake. Indeed, our earth is so infinitesimal in comparison with the whole universe, we, the only thinking beings, so far as we know, in the whole of space, are to all appearances so accidental, so far removed from the main scheme of the universe, that it is *a priori* all too probable that any meaning that the universe as a whole may have, would entirely transcend our terrestrial experience, and so be totally unintelligible to us. In this event, we should have had no foothold from which to start our exploration of the true meaning of the universe.

Although this is the most likely event, it is not impossible that some of the shadows thrown on to the walls of our cave might suggest objects and operations with which we cave-dwellers were already familiar in our caves. The shadow of a falling body behaves like a falling body, and so would remind us of bodies we had our-

selves let fall; we should be tempted to interpret such shadows in mechanical terms. This explains the mechanical physics of the last century; the shadows reminded our scientific predecessors of the behaviour of jellies, spinning-tops, thrust-bars, and cog-wheels, so that they, mistaking the shadow for the substance, believed they saw before them a universe of jellies and mechanical devices. We know now that the interpretation is conspicuously inadequate: it fails to explain the simplest phenomena, the propagation of a sunbeam, the composition of radiation, the fall of an apple, or the whirl of electrons in the atom.

Again, the shadow of a game of chess, played by the actors out in the sunlight, would remind us of the games of chess we had played in our cave. Now and then we might recognize knights' moves, or observe castles moving simultaneously with kings and queens, or discern other characteristic moves so similar to those we were accustomed to play that they could not be attributed to chance. We would no longer think of the external reality as a machine; the details of its operation might be mechanical, but in essence it would be a reality of thought: we should recognize the chess players out in the sunlight as beings governed by minds like our own; we should find the counterpart of our own thoughts in the reality which was for ever inaccessible to our direct observation.

And when scientists study the world of phenomena, the shadows which nature throws on to the wall of our cave, they do not find these shadows totally unintelligible, and neither do they seem to represent unknown or unfamiliar objects. Rather, it seems to me, we can recognize chess players outside in the sunshine who appear to be very well acquainted with the rules of the game *as we have formulated them in our cave*. To drop our metaphor, nature seems very conversant with the rules of pure mathematics, as our mathematicians have formulated them in their studies, out of their own inner consciousness and without drawing to any appreciable extent on their experience of the outer world. By "pure mathematics" is meant those departments of mathematics which are creations of pure thought, of reason operating solely within her own sphere, as contrasted with "applied mathematics" which reasons about the external world, after first taking some supposed property of the external world as its raw

material. Descartes, looking round for an example of the produce of pure thought uncontaminated by observation (rationalism), chose the fact that the sum of the three angles of a triangle was necessarily equal to two right angles. It was, as we now know, a singularly unfortunate choice. Other choices, far less open to objection, might easily have been made, as, for instance, the laws of probability, the rules of manipulation of "imaginary" numbers—i.e., numbers containing the square roots of negative quantities—or multi-dimensional geometry. All these branches of mathematics were originally worked out by the mathematician in terms of abstract thought, practically uninfluenced by contact with the outer world, and drawing nothing from experience: they formed

an independent world
created out of pure intelligence.

And now it emerges that the shadow-play which we describe as the fall of an apple to the ground, the ebb and flow of the tides, the motion of electrons in the atom, are produced by actors who seem very conversant with these purely mathematical concepts—with our rules of our game of chess, which we formulated long before we discovered that the shadows on the wall were also playing chess.

When we try to discover the nature of the reality behind the shadows, we are confronted with the fact that all discussion of the ultimate nature of things must necessarily be barren unless we have some extraneous standards against which to compare them. For this reason, to borrow Locke's phrase, " the real essence of substances" is for ever unknowable. We can only progress by discussing the laws which govern the changes of substances, and so produce the phenomena of the external world. These we can compare with the abstract creations of our own minds.

For instance, a deaf engineer studying the action of a pianola might try first to interpret it as a machine, but would be baffled by the continuous reiteration of the intervals 1, 5, 8, 13 in the motions of its trackers. A deaf musician, although he could hear nothing, would immediately recognize this succession of numbers as the intervals of the common chord, while other successions of less frequent occurrence would suggest other musical chords. In this way he would

recognize a kinship between his own thoughts and the thoughts which had resulted in the making of the pianola; he would say that it had come into existence through the thought of a musician. In the same way, a scientific study of the action of the universe has suggested a conclusion which may be summed up, though very crudely and quite inadequately, because we have no language at our command except that derived from our terrestrial concepts and experiences, in the statement that the universe appears to have been designed by a pure mathematician.

This statement can hardly hope to escape challenge on the ground that we are merely moulding nature to our pre-conceived ideas. The musician, it will be said, may be so engrossed in music that he would contrive to interpret every piece of mechanism as a musical instrument; the habit of thinking of all intervals as musical intervals may be so ingrained in him that if he fell downstairs and bumped on stairs numbered 1, 5, 8 and 13 he would see music in his fall. In the same way a cubist painter can see nothing but cubes in the indescribable richness of nature—and the unreality of his pictures shows how far he is from understanding nature; his cubist spectacles are mere blinkers which prevent his seeing more than a minute fraction of the great world around him. So, it may be suggested, the mathematician only sees nature through the mathematical blinkers he has fashioned for himself. We may be reminded that Kant, discussing the various modes of perception by which the human mind apprehends nature, concluded that it is specially prone to see nature through mathematical spectacles. Just as a man wearing blue spectacles would see only a blue world, so Kant thought that, with our mental bias, we tend to see only a mathematical world. Does our argument merely exemplify this old pitfall, if such it is?

A moment's reflection will show that this can hardly be the whole story. The new mathematical interpretation of nature cannot all be in our spectacles—in our subjective way of regarding the external world—since if it were we should have seen it long ago. The human mind was the same in quality and mode of action a century ago as now; the recent great change in scientific outlook has resulted from a vast advance in scientific knowledge and not from any change in the human mind; we have found something new and hitherto unknown

in the objective universe outside ourselves. Our remote ancestors tried to interpret nature in terms of anthropomorphic concepts of their own creation and failed. The efforts of our nearer ancestors to interpret nature on engineering lines proved equally inadequate. Nature refused to accommodate herself to either of these man-made moulds. On the other hand, our efforts to interpret nature in terms of the concepts of pure mathematics have, so far, proved brilliantly successful. It would now seem to be beyond dispute that in some way nature is more closely allied to the concepts of pure mathematics than to those of biology or of engineering, and even if the mathematical interpretation is only a third man-made mould, it at least fits objective nature incomparably better than the two previously tried.

A hundred years ago, when scientists were trying to interpret the world mechanically, no wise man came forward to assure them that the mechanical view was bound to prove a misfit in the end—that the phenomenal universe would never make sense until it was projected on to a screen of pure mathematics: had they brought forward a convincing argument to this effect, science might have been saved much fruitless labour. If the philosopher now says: "What you have found is nothing new: I could have told you that it must be so all the time," the scientist may reasonably inquire: "Why, then, did you not tell us so, when we should have found the information of real value?"

Our contention is that the universe now appears to be mathematical in a sense different from any which Kant contemplated or possibly could have contemplated—in brief, the mathematics enters the universe from above instead of from below.

In one sense it may be argued that everything is mathematical. The simplest form of mathematics is arithmetic, the science of numbers and quantities—and these permeate the whole of life. For instance, commerce, which consists largely of the arithmetical operations of book-keeping, stock-taking and so on, is in a sense a mathematical occupation—but it is not in this sense that the universe now appears to be mathematical.

Again, every engineer has to be something of a mathematician; if he is to calculate and predict the mechanical behaviour of bodies

with accuracy, he must use mathematical knowledge and look at his problems through mathematical spectacles—but again it is not in this way that science has begun to see the universe as mathematical. The mathematics of the engineer differs from the mathematics of the shopkeeper only in being far more complex. It is still a mere tool for calculation; instead of evaluating stock-in-trade or profits, it evaluates stresses and strains or electric currents.

On the other hand, Plutarch records that Plato used to say that God for ever geometrizes—*Πλάτων ἔλεγε τὸν θεὸν ἀεὶ γεωμετρεῖν*—and he sets an imaginary symposium at work to discuss what Plato meant by this. Clearly he meant something quite different in kind from what we mean when we say that the banker for ever arithmetizes. Among the illustrations given by Plutarch are: that Plato had said that geometry sets limits to what would otherwise be unlimited, and that he had stated that God had constructed the universe on the basis of the five regular solids—he believed that the particles of earth, air, fire and water had the shapes of cubes, octahedra, tetrahedra and icosahedra, while the universe itself was shaped like a dodecahedron. To these may perhaps be added Plato's belief that the distances of the sun, moon and planets were "in the proportion of the double intervals," by which he meant the sequence of integers which are powers of either 2 or 3—namely 1, 2, 3, 4, 8, 9, 27.

If any of these considerations retain any shred of validity today, it is the first—the universe of the theory of relativity is finite just because it is geometrical. The idea that the four elements and the universe were in any way related to the five regular solids was, of course, mere fancy, and the true distances of the sun, moon and planets bear absolutely no relation to Plato's numbers.

Two thousand years after Plato, Kepler spent much time and energy in trying to relate the sizes of the planetary orbits to musical intervals and geometrical constructions; perhaps he, too, hoped to discover that the orbits had been arranged by a musician or a geometer. Indeed, at one time he believed he had found that the ratios of the orbits were related to the geometry of the five regular solids. If this supposed fact had been known to Plato, what a proof he might have seen in it of the geometrizing propensities of the deity! Kepler himself wrote: "The intense pleasure I have received from this dis-

covery can never be told in words." It need hardly be said that the great discovery was fallacious. Indeed, our modern minds immediately dismiss it as ridiculous; we find it impossible to think of the solar system as a finished product, the same today as when it came from the hand of its maker; we can only think of it as something continually changing and evolving, working out its own future from its past. Yet if we can momentarily give a sufficiently medieval cast to our thoughts, and imagine anything so fanciful as that Kepler's conjecture should have been true, it is clear that he would have been entitled to draw some sort of inference from it. The mathematics which he had found in the universe would have been something more than he had himself put in, and he could legitimately have argued that there was inherent in the universe a mathematics additional to that which he had used to unravel its design; he might have argued, in anthropomorphic language, that his discovery suggested that the universe had been designed by a geometer. And he need no more have troubled about the criticism that the mathematics he had discovered resided merely in his own mathematical spectacles, than the angler who catches a big fish by using a little fish as bait need be worried by the comment: "Yes, but I saw you put the fish in yourself."

Let us take a more modern and less fanciful example of the same thing. Fifty years ago, when there was much discussion on the problem of communicating with Mars, it was desired to notify the supposed Martians that thinking beings existed on the planet Earth, but the difficulty was to find a language understood by both parties. The suggestion was made that the most suitable language was that of pure mathematics; it was proposed to light chains of bonfires in the Sahara, to form a diagram illustrating the famous theorem of Pythagoras, that the squares on the two smaller sides of a right-angled triangle are together equal to the square on the greatest side. To most of the inhabitants of Mars such signals would convey no meaning, but it was argued that mathematicians on Mars, if such existed, would surely recognize them as the handiwork of mathematicians on earth. In so doing, they would not be open to the reproach that they saw mathematics in everything. And it seems to me that the situation is similar, *mutatis mutandis*, with the signals from the outer world of

reality which form the shadows on the walls of the cave in which we are imprisoned. We cannot interpret these as shadows cast by living actors nor as shadows cast by a machine, but the pure mathematician recognizes them as representing the kind of ideas with which he is already familiar in his studies.

We could not, of course, draw any conclusion from this if the concepts of pure mathematics which we find to be inherent in the structure of the universe were merely part of, or had been introduced through, the concepts of applied mathematics which we used to discover the workings of the universe. It would prove nothing if nature had merely been found to act in accordance with the concepts of applied mathematics; these concepts were specially and deliberately designed by man to fit the workings of nature. Thus it may still be objected that even our pure mathematics does not in actual fact represent a creation of our own minds so much as an effort, based on forgotten or subconscious memories, to understand the workings of nature. If so, it is not surprising that nature should be found to work according to the laws of pure mathematics. It cannot, of course, be denied that some of the concepts with which the pure mathematician works are taken direct from his experience of nature. An obvious instance is the concept of quantity, but this is so fundamental that it is hard to imagine any scheme of nature from which it was entirely excluded. Other concepts borrow at least something from experience; for instance, multi-dimensional geometry, which clearly originated out of experience of the three dimensions of space. If, however, the more intricate concepts of pure mathematics have been transplanted from the workings of nature, they must have been buried very deep indeed in our sub-conscious minds. This very controversial possibility is one which cannot be entirely dismissed, but it is exceedingly hard to believe that such intricate concepts as a finite curved space and an expanding space can have entered into pure mathematics through any sort of unconscious or sub-conscious experience of the workings of the actual universe. In any event, it can hardly be disputed that nature and our conscious mathematical minds work according to the same laws. She does not model her behaviour, so to speak, on that forced on us by our whims and passions, or on that of our muscles and joints, but on that of our thinking minds. This

remains true whether our minds impress their laws on nature, or she impresses her laws on us, and provides a sufficient justification for thinking of the universe as being a mathematical design. Lapsing back again into the crudely anthropomorphic language we have already used, we may say that we have already considered with disfavour the possibility of the universe having been planned by a biologist or an engineer; from the intrinsic evidence of his creation, the Great Architect of the Universe now begins to appear as a pure mathematician.

Personally, I feel that this train of thought may, very tentatively, be carried a stage further, although it is difficult to express it in exact words, again because our mundane vocabulary is circumscribed by our mundane experience. The terrestrial pure mathematician does not concern himself with material substance, but with pure thought. His creations are not only created by thought but consist of thought, just as the creations of the engineer consist of engines. And the concepts which now prove to be fundamental to our understanding of nature—a space which is finite; a space which is empty, so that one point differs from another solely in the properties of the space itself; four-dimensional, seven- and more dimensional spaces; a space which for ever expands; a sequence of events which follows the laws of probability instead of the law of causation—or, alternately, a sequence of events which can only be fully and consistently described by going outside space and time—all these concepts seem to my mind to be structures of pure thought, incapable of realization in any sense which would properly be described as material.

For instance, any one who has written or lectured on the finiteness of space is accustomed to the objection that the concept of a finite space is self-contradictory and nonsensical. If space is finite, our critics say, it must be possible to go out beyond this finite space, and what can we possibly find beyond it except more space, and so on *ad infinitum?*—which proves that space cannot be finite. And again, they say, if space is expanding, what can it possibly expand into, if not into more space?—which again proves that what is expanding can only be a part of space, so that the whole of space cannot expand.

The twentieth-century critics who make these comments are still

in the state of mind of the nineteenth-century scientists; they take it for granted that the universe must admit of material representation. If we grant their premisses, we must, I think, also grant their conclusion—that we are talking nonsense—for their logic is irrefutable. But modern science cannot possibly grant their conclusion; it insists on the finiteness of space at all costs. This, of course, means that we must deny the premisses which our critics unknowingly assume. The universe cannot admit of material representation, and the reason, I think, is that it has become a mere mental concept.

It is the same, I think, with other more technical concepts, typified by the "exclusion principle," which seem to imply a sort of "action-at-a-distance" in both space and time—as though every bit of the universe knew what other distant bits were doing, and acted accordingly. To my mind, the laws which nature obeys are less suggestive of those which a machine obeys in its motion than of those which a musician obeys in writing a fugue, or a poet in composing a sonnet. The motions of electrons and atoms do not resemble those of the parts of a locomotive so much as those of the dancers in a cotillion. And if the "true essence of substances" is for ever unknowable, it does not matter whether the cotillion is danced at a ball in real life, or on a cinematograph screen, or in a story of Boccaccio. If all this is so, then the universe can be best pictured, although still very imperfectly and inadequately, as consisting of pure thought, the thought of what, for want of a wider word, we must describe as a mathematical thinker.

And so we are led into the heart of the problem of the relation between mind and matter. Atomic disturbances in the distant sun cause it to emit light and heat. After "travelling through the ether" for eight minutes, some of this radiation may fall on our eyes, causing a disturbance on the retina, which travels along the optic nerve to the brain. Here it is perceived as a sensation by the mind; this sets our thoughts in action and results in, let us say, poetic thoughts about the sunset. There is a continuous chain, *A*, *B*, *C*, *D* . . . *X*, *Y*, *Z*, connecting *A* the poetic thought—through *B* the thinking mind, *C* the brain, *D* the optic nerve, and so on—with *Z* the atomic disturbance in the sun. The thought *A* results from the distant disturbance *Z*, just as the ringing of a bell results from pulling a distant

bell-rope. We can understand how pulling a material rope can cause a material bell to ring, because there is a material connexion all the way. But it is far less easy to see how a disturbance of material atoms can cause a poetic thought to originate, because the two are so entirely dissimilar in nature.

For this reason, Descartes insisted that there could be no possible connexion between mind and matter. He believed they were two entirely distinct kinds of entity, the essence of matter being extension in space, and that of mind being thought. And this led him to maintain that there were two distinct worlds, one of mind and one of matter, running, so to speak, independent courses on parallel rails without ever meeting.

Berkeley and the idealist philosophers agreed with Descartes that if mind and matter were fundamentally of different natures they could never interact. But they insisted that they continually do interact. Therefore, they argued, matter must be of the same nature as mind, so that, in the terminology of Descartes, the essence of matter must be thought rather than extension. Expressed in detail, their contention was that causes must be essentially of the same nature as their effects; if *B* on our chain produces *A*, then *B* must be of the same essential nature as *A*, and *C* as *B*, and so on. Thus *Z* also must be of the same essential nature as *A*. Now the only links of the chain of which we have any *direct* knowledge are our own thoughts and sensations *A*, *B*; we know of the existence and nature of the remote links *X*, *Y*, *Z* only by inference—from the effects they transmit to our minds through our senses. Berkeley, maintaining that the unknown distant links *X*, *Y*, *Z* must be of the same nature as the known near links *A*, *B*, argued that they must be of the nature of thoughts or ideas, "since after all there is nothing like an idea except an idea." A thought or idea cannot, however, exist without a mind in which to exist. We may say an object exists in our minds while we are conscious of it, but this will not account for its existence during the time we are not conscious of it. The planet Pluto, for instance, was in existence long before any human mind suspected it, and was recording its existence on photographic plates long before any human eye saw it. Considerations such as these led Berkeley to postulate an Eternal Being, in whose mind all objects existed. And so, in the

stately and sonorous diction of a bygone age, he summed up his philosophy in the words :—

> All the choir of heaven and furniture of earth, in a word all those bodies which compose the mighty frame of the world, have not any substance without the mind. . . . So long as they are not actually perceived by me, or do not exist in my mind, or that of any other created spirit, they must either have no existence at all, or else subsist in the mind of some Eternal Spirit.

Modern science seems to me to lead, by a very different road, to a not altogether dissimilar conclusion. Biology, studying the connexion between the earlier links of the chain, *A*, *B*, *C*, *D*, seems to be moving towards the conclusion that these are all of the same general nature. This is occasionally stated in the specific form that, as biologists believe *C*, *D* to be mechanical and material, *A*, *B* must also be mechanical and material, but apparently there would be at least equal warrant for stating it in the form that as *A*, *B* are mental, *C*, *D*, must also be mental. Physical science, troubling little about *C*, *D*, proceeds directly to the far end of the chain; its business is to study the workings of *X*, *Y*, *Z*. And, as it seems to me, its conclusions suggest that the end links of the chain, whether we go to the cosmos as a whole or to the innermost structure of the atom, are of the same nature as *A*, *B*—of the nature of pure thought; we are led to the conclusions of Berkeley, but we reach them from the other end. Because of this, we come upon the last of Berkeley's three alternatives first, and the others appear unimportant by comparison. It does not matter whether objects "exist in my mind, or that of any other created spirit" or not; their objectivity arises from their subsisting "in the mind of some Eternal Spirit."

This may suggest that we are proposing to discard realism entirely, and enthrone a thoroughgoing idealism in its place. Yet this, I think, would be too crude a statement of the situation. If it is true that the "real essence of substances" is beyond our knowledge, then the line of demarcation between realism and idealism becomes very blurred indeed; it becomes little more than a relic of a past age in which reality was believed to be identical with mechanism. Objective realities exist, because certain things affect your consciousness and mine in the same way, but we are assuming something we have no right to assume if we label them as either "real" or "ideal." The true label

is, I think, "mathematical," if we can agree that this is to connote the whole of pure thought, and not merely the studies of the professional mathematician. Such a label does not imply anything as to what things are in their ultimate essence, but merely something as to how they behave.

The label we have selected does not, of course, relegate matter into the category of hallucination or dreams. The material universe remains as substantial as ever it was, and this statement must, I think, remain true through all changes of scientific or philosophical thought.

For substantiality is a purely mental concept measuring the direct effect of objects on our sense of touch. We say that a stone or a motor car is substantial, while an echo or a rainbow is not. This is the ordinary definition of the word, and it is a mere absurdity, a contradiction in terms, to say that stones and motor cars can in any way become insubstantial, or even less substantial, because we now associate them with mathematical formulæ and thoughts, or kinks in empty space, rather than with crowds of hard particles. Dr. Johnson is reported to have expressed his opinion on Berkeley's philosophy by dashing his foot against a stone, and saying: "No, sir, I disprove it thus." This little experiment had, of course, not the slightest bearing on the philosophical problem it claimed to solve; it merely verified the substantiality of matter. And, however science may progress, stones must always remain substantial bodies, just because they and their class form the standard by which we define the quality of substantiality.

It has been suggested that the lexicographer might really have disproved the Berkeleian philosophy if he had chanced to kick, not a stone but a hat, in which some small boy had surreptitiously placed a brick; we are told that "the element of surprise is sufficient warrant for external reality," and that "a second warrant is permanence with change—permanence in your own memory, change in externality." This, of course, merely disproves the solipsist error of "all this is a creation of my own mind, and exists in no other mind," but it is hard to do anything in life which does not disprove this. The argument from surprise, and from new knowledge in general, is powerless against the concept of a universal mind of which your mind and mine, the mind which surprises and that which is surprised, are units

or even excrescences. Each individual brain cell cannot be acquainted with all the thoughts which are passing through the brain as a whole.

Yet the fact that we possess no absolute extraneous standard against which to measure substantiality does not preclude our saying that two things have the same degree, or different degrees, of substantiality. If I dash my foot against a stone in my dreams, I shall probably waken up with a pain in my foot, to discover that the stone of my dreams was literally a creation of my mind and of mine alone, prompted by a nerve-impulse originating in my foot. This stone may typify the category of hallucinations or dreams; it is clearly less substantial than that which Johnson kicked. Creations of an individual mind may reasonably be called less substantial than creations of a universal mind. A similar distinction must be made between the space we see in a dream and the space of everyday life; the latter, which is the same for us all, is the space of the universal mind. It is the same with time, the time of waking life, which flows at the same even rate for us all, being the time of the universal mind. Again we may think of the laws to which phenomena conform in our waking hours, the laws of nature, as the laws of thought of a universal mind. The uniformity of nature proclaims the self-consistency of this mind.

This concept of the universe as a world of pure thought throws a new light on many of the situations we have encountered in our survey of modern physics. We can now see how the ether, in which all the events of the universe take place, could reduce to a mathematical abstraction, and become as abstract and as mathematical as parallels of latitude and meridians of longitude. We can also see why energy, the fundamental entity of the universe, had again to be treated as a mathematical abstraction—the constant of integration of a differential equation.

The same concept implies, of course, that the final truth about a phenomenon resides in the mathematical description of it; so long as there is no imperfection in this our knowledge of the phenomenon is complete. We go beyond the mathematical formula at our own risk; we may find a model or picture which helps us to understand it, but we have no right to expect this, and our failure to find such a model or picture need not indicate that either our reasoning or our

knowledge is at fault. The making of models or pictures to explain mathematical formulæ and the phenomena they describe, is not a step towards, but a step away from, reality; it is like making graven images of a spirit. And it is as unreasonable to expect these various models to be consistent with one another as it would be to expect all the statues of Hermes, representing the god in all his varied activities—as messenger, herald, musician, thief and so on—to look alike. Some say that Hermes is the wind; if so, all his attributes are wrapped up in his mathematical description, which is neither more nor less than the equation of motion of a compressible fluid. The mathematician will know how to pick out the different aspects of this equation which represent the conveying and announcing of messages, the creation of musical tones, the blowing away of our papers, and so forth. He will hardly need statues of Hermes to remind him of them, although, if he is to rely on statues, nothing less than a whole row, all different, will suffice. All the same, some mathematical physicists are still busily at work making graven images of the concepts of the wave-mechanics.

In brief, a mathematical formula can never tell us what a thing is, but only how it behaves; it can only specify an object through its properties. And these are unlikely to coincide *in toto* with the properties of any single macroscopic object of our everyday life.

This point of view brings us relief from many of the difficulties and apparent inconsistencies of present-day physics. We need no longer discuss whether light consists of particles or waves; we know all there is to be known about it if we have found a mathematical formula which accurately describes its behaviour, and we can think of it as either particles or waves according to our mood and the convenience of the moment. On our days of thinking of it as waves, we may if we please imagine an ether to transmit the waves, but this ether will vary from day to day; we have seen how it will vary each time our speed of motion varies. In the same way, we need not discuss whether the wave-system of a group of electrons exists in a three-dimensional space, or in a many-dimensional space, or not at all. It exists in a mathematical formula; this, and nothing else, expresses the ultimate reality, and we can picture it as representing waves in three, six or more dimensions whenever we so please. We can also

interpret it as not representing waves at all; in so doing we shall be following Heisenberg and Dirac. It is generally simplest to interpret it as representing waves in a space having three dimensions for each electron, just as it is simplest to interpret the macroscopic universe as an array of objects in three dimensions only, and its phenomena as an array of events in four dimensions, but none of these interpretations possesses any unique or absolute validity.

On this view, we need find no mystery in the nature of the rolling contact of our consciousness with the empty soap bubble we call space-time (p. 80), for it reduces merely to a contact between mind and a creation of mind—like the reading of a book, or listening to music. It is probably unnecessary to add that, on this view of things, the apparent vastness and emptiness of the universe, and our own insignificant size therein, need cause us neither bewilderment nor concern. We are not terrified by the sizes of the structures which our own thoughts create, nor by those that others imagine and describe to us. In Du Maurier's story, Peter Ibbetson and the Duchess of Towers continued to build vast dream-palaces and dream-gardens of ever-increasing size, but felt no terror at the size of their mental creations. The immensity of the universe becomes a matter of satisfaction rather than awe; we are citizens of no mean city. Again, we need not puzzle over the finiteness of space; we feel no curiosity as to what lies beyond the four walls which bound our vision in a dream.

It is the same with time, which, like space, we must think of as of finite extent. As we trace the stream of time backwards, we encounter many indications that, after a long enough journey, we must come to its source, a time before which the present universe did not exist. Nature frowns upon perpetual motion machines and it is *a priori* very unlikely that her universe will provide an example, on the grand scale, of the mechanism she abhors. And a detailed consideration of nature confirms this. The science of thermodynamics explains how everything in nature passes to its final state by a process which is designated the "increase of entropy." Entropy must for ever increase: it cannot stand still until it has increased so far that it can increase no further. When this stage is reached, further progress will be impossible, and the universe will be dead. Thus, unless this whole branch of science is wrong, nature permits herself, quite literally, only two

alternatives, progress and death: the only standing still she permits is in the stillness of the grave.

Some scientists, although not, I think, very many, would dissent from this last view. While they do not dispute that the present stars are melting away into radiation, they maintain that, somewhere out in the remote depths of space, this radiation may be reconsolidating itself again into matter. A new heaven and a new earth may, they suggest, be in process of being built, not out of the ashes of the old, but out of the radiation set free by the combustion of the old. In this way they advocate what may be described as a cyclic universe; while it dies in one place the products of its death are busy producing new life in others.

This concept of a cyclic universe is entirely at variance with the well-established principle of the second law of thermodynamics, which teaches that entropy must for ever increase, and that cyclic universes are impossible in the same way, and for much the same reason, as perpetual motion machines are impossible. That this law may fail under astronomical conditions of which we have no knowledge is certainly conceivable, although I imagine the majority of serious scientists consider it very improbable. There is, of course, no denying that the concept of a cyclic universe is far the more popular of the two. Most men find the final dissolution of the universe as distasteful a thought as the dissolution of their own personality, and man's strivings after personal immortality have their macroscopic counterpart in these more sophisticated strivings after an imperishable universe.

The more orthodox scientific view is that the entropy of the universe must for ever increase to its final maximum value. It has not yet reached this: we should not be thinking about it if it had. It is still increasing rapidly, and so must have had a beginning; there must have been what we may describe as a "creation" at a time not infinitely remote.

If the universe is a universe of thought, then its creation must have been an act of thought. Indeed the finiteness of time and space almost compel us, of themselves, to picture the creation as an act of thought; the determination of the constants such as the radius of the universe and the number of electrons it contained imply thought, whose rich-

ness is measured by the immensity of these quantities. Time and space, which form the setting for the thought, must have come into being as part of this act. Primitive cosmologies pictured a creator working in space and time, forging sun, moon and stars out of already existent raw material. Modern scientific theory compels us to think of the creator as working outside time and space, which are part of his creation, just as the artist is outside his canvas. It accords with the conjecture of Augustine: "Non in tempore, sed cum tempore, finxit Deus mundum." Indeed, the doctrine dates back as far as Plato :—

> Time and the heavens came into being at the same instant, in order that, if they were ever to dissolve, they might be dissolved together. Such was the mind and thought of God in the creation of time.

And yet, so little do we understand time that perhaps we ought to compare the whole of time to the act of creation, the materialization of the thought.

It may be objected that our whole argument is based on the assumption that the present mathematical interpretation of the physical world is in some way unique, and will prove to be final. To resume our metaphor, it may be said that to describe the reality as a game of chess is only a convenient fiction: other fictions might describe the motions of the shadows equally well. The answer is that, so far as our present knowledge goes, other fictions would not describe them so fully, so simply, or so adequately. The man who does not play chess says: "A piece of white wood, carved to look rather like a horse's head stuck on a pedestal, was taken from the bottom square next but one to the right-hand corner and moved to . . ." and so on. The chess-player says: "White: Kt to KB3," and his account not only explains the move fully and briefly, but also relates it to a larger scheme of things. In science, so long as our knowledge remains incomplete, the simplest explanation carries conviction in proportion to its simplicity. And it has merit beyond that of mere simplicity: it has the highest probability of being the true explanation. Thus while it must be fully admitted that the mathematical explanation may prove neither to be final nor the simplest possible, we can unhesitatingly say that it is the simplest and most complete so far found, so that, relative to our present knowledge, it has the

greatest chance of being the explanation which lies nearest to the truth.

Some readers may not assent to this, on the grounds that the present-day mathematical interpretation of nature is likely to prove a mere half-way house to a new mechanical interpretation. Our modern minds have, I think, a bias towards mechanical interpretations. Part may be due to our early scientific training; part perhaps to our continually seeing everyday objects behaving in a mechanical way, so that a mechanical explanation looks natural and is easily comprehended. Yet in a completely objective survey of the situation, the outstanding fact would seem to be that mechanics has already shot its bolt and has failed dismally, on both the scientific and philosophical side. If anything is destined to replace mathematics, there would seem to be specially long odds against it being mechanics.

It is too often overlooked that we can only discuss these questions in terms of probabilities. The man of science is accustomed to the reproach that he changes his views all the time, with the accompanying implication that what he says need not be taken too seriously. It is no true reproach that in exploring the river of knowledge he occasionally goes down a backwater instead of continuing along the main stream; no explorer can be sure that a backwater is such, and nothing more, until he has been down it. What is more serious, and beyond the control of the explorer, is that the river is a winding one, flowing now east, now west. At one moment the explorer says: "I am going downstream, and, as I am going towards the west, the ocean which is reality seems most likely to lie in the westerly direction." And later, when the river has turned east, he says: "It now looks as though reality is in the east." No scientist who has lived through the last thirty years is likely to be too dogmatic either as to the future course of the stream or as to the direction in which reality lies: he knows from his own experience how the river not only for ever broadens but also repeatedly winds, and, after many disappointments, he has given up thinking at every turn that he is at last in the presence of the

murmurs and scents of the infinite sea.

With this caution in mind, it seems at least safe to say that the river

of knowledge has made a sharp bend in the last few years. Thirty years ago, we thought, or assumed, that we were heading towards an ultimate reality of a mechanical kind. It seemed to consist of a fortuitous jumble of atoms, which was destined to perform meaningless dances for a time under the action of blind purposeless forces, and then fall back to form a dead world. Into this wholly mechanical world, through the play of the same blind forces, life had stumbled by accident. One tiny corner at least, and possibly several tiny corners, of this universe of atoms had chanced to become conscious for a time, but was destined in the end, still under the action of blind mechanical forces, to be frozen out and again leave a lifeless world.

Today there is a wide measure of agreement, which on the physical side of science approaches almost to unanimity, that the stream of knowledge is heading towards a non-mechanical reality; the universe begins to look more like a great thought than like a great machine. Mind no longer appears as an accidental intruder into the realm of matter; we are beginning to suspect that we ought rather to hail it as the creator and governor of the realm of matter—not, of course, our individual minds, but the mind in which the atoms out of which our individual minds have grown exist as thoughts.

The new knowledge compels us to revise our hasty first impressions that we had stumbled into a universe which either did not concern itself with life or was actively hostile to life. The old dualism of mind and matter, which was mainly responsible for the supposed hostility, seems likely to disappear, not through matter becoming in any way more shadowy or insubstantial than heretofore, or through mind becoming resolved into a function of the working of matter, but through substantial matter resolving itself into a creation and manifestation of mind. We discover that the universe shows evidence of a designing or controlling power that has something in common with our own individual minds—not, so far as we have discovered, emotion, morality, or æsthetic appreciation, but the tendency to think in the way which, for want of a better word, we describe as mathematical. And while much in it may be hostile to the material appendages of life, much also is akin to the fundamental activities of life; we are not so much strangers or intruders in the universe as we at first thought. Those inert atoms in the

primeval slime which first began to foreshadow the attributes of life were putting themselves more, and not less, in accord with the fundamental nature of the universe.

So at least we are tempted to conjecture today, and yet who knows how many more times the stream of knowledge may turn on itself? And with this reflection before us, we may well conclude by adding, what might well have been interlined into every paragraph, that everything that has been said, and every conclusion that has been tentatively put forward, is quite frankly speculative and uncertain. We have tried to discuss whether present-day science has anything to say on certain difficult questions, which are perhaps set for ever beyond the reach of human understanding. We cannot claim to have discerned more than a very faint glimmer of light at the best; perhaps it was wholly illusory, for certainly we had to strain our eyes very hard to see anything at all. So that our main contention can hardly be that the science of today has a pronouncement to make, perhaps it ought rather to be that science should leave off making pronouncements: the river of knowledge has too often turned back on itself.

BOOK II

ANIMAL BIOLOGY

BY J. B. S. HALDANE
AND JULIAN HUXLEY

NOTE

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CHAPTER ONE

INTRODUCTION

ZOOLOGY OR ANIMAL BIOLOGY is that branch of science which deals with animals. About half a million different sorts or species of animals have already been described and named, each breeding true to its own special characteristics, each different from all others. The number of fresh species discovered, described and named every year is about two hundred, and this number is at present increasing, not decreasing, year by year.

Animals inhabit sea, fresh water, land, and air, or they may live on or in the bodies of other animals or plants. Their range of size is enormous. The malarial parasite is so small as easily to inhabit the interior of a human red blood corpuscle, of which five million are normally contained in a cubic millimetre of blood;* while the sulphur-bottom whale (*Balaenoptera sulphureus*), the largest animal known, may reach a length of 95 feet and a weight of 147 tons, or nearly three times as much as most express engines (Fig. 92). Their shape is as various as their habits or their size. Some, like certain radiolaria, form beautiful geometrical designs; others are almost shapeless, like many parasites (Fig. 1) and sponges; some resemble plants (Fig. 69); still others, such as the nematode worms, look like long threads; let alone all those innumerable shapes of bird and fish and mammal, crab and spider and insect, that we all know.

It is obvious that any study of all these creatures, their structure and mode of working, their habits and their history, will soon give us an enormous body of facts which will be overwhelming unless we classify them properly. Broadly speaking, we want, first of all, to find out how a particular animal works, considered as a piece of living mechanism; and to compare the ways of working of various animals. That is animal physiology. And secondly, we want to know all we can about the structural plan of animals, to know how that structure develops, and to compare the structure of different animals. That is animal morphology, the science of form. Finally, we want to understand, if possible, how and why it is that the different individuals and

* About one-sixtieth of an average drop.

species of animals are what they are—their history and as much as possible of the causes of that history. That is the science of animal evolution and heredity, sometimes called genetics (although this term is often restricted to heredity alone).

There remains the problem as to the fundamental difference between plants and animals. Why do we call this organism a plant, this other organism an animal? Most people would not hesitate, but would say that the animal moved while the plant did not; that the animal was conscious while the plant was not; that the animal devoured its food while the plant absorbed its nutriment from its surroundings. None of these criteria, however, is absolute. Many animals, like coral polyps or sea squirts, are as rooted to the spot as most plants; while some undoubted plants move about. He would be a very bold man who asserted that a sponge, an undoubted animal,

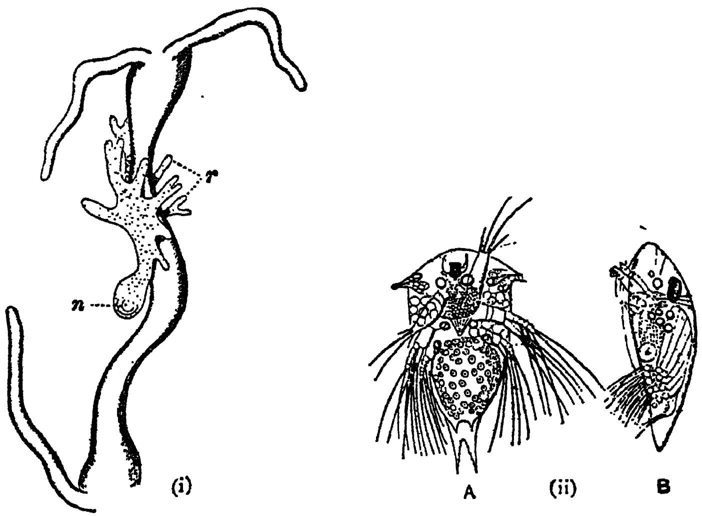


FIG. 1. Parasitism and recapitulation as illustrated by the Crustacean parasite Sacculina. (i) Sacculina developing inside a spider crab (Inachus). The mid-gut of the spider crab is shown, with the parasite overlying it (×2): *n*, body-rudiment of the parasite; *r*, its "roots," by which it sucks nutriment from the tissues of its host. (ii) Development of Sacculina. (A) Earliest free swimming stage or Nauplius with three pairs of appendages. In this stage it closely resembles the larvæ of many other Crustacea. (B) Later stage, in which it attaches itself to its host (magnified). (*Cambridge Natural History*, iv, 1909.)

possessed a higher level of consciousness than a mushroom or a wallflower; while many animal parasites absorb their food from the medium which bathes them.

As a matter of fact, the only valid distinction between plants and animals is concerned with the type of foodstuffs which they can utilize. All organisms, plant or animal, need carbon, hydrogen, nitrogen, and oxygen to build the bulk of their bodies. Green plants can, with the aid of sunlight, obtain carbon from the carbon dioxide of the air or water in which they live. They can obtain their hydrogen from water and salts, their oxygen directly from the air, their nitrogen from simple mineral salts like nitrates. In other words, the green plant can build up living protoplasm from elements and the simplest compounds. Every particle of living matter added to a green plant means the creation of a new kind of material combination. Animals, on the other hand, cannot achieve this synthesis. They have to be provided with highly elaborate compounds, all of which in the long run owe their existence to the manufacturing powers of plants. An animal cannot obtain its carbon from any compound less complex than a sugar, a starch, or a fat; for its nitrogen it must be provided with proteins, or at least with the constituent parts of proteins known as amino-acids, which are already of considerable complexity. Animals are in the long run always dependent upon green plants; they are, one might almost say, parasitic upon plants. Green plants by the same token are parasitic upon the sun; they live by stealing energy from his rays.

There are other plants besides green plants: fungi and bacteria contain no chlorophyll. Most fungi are as dependent as are animals upon the previous activities of other organisms; they can only live where decay has provided them with raw materials. But even so they are not so helpless as animals, and can obtain their food from less complex compounds.

Among the bacteria are forms which show quite extraordinary modes of nutrition. The most interesting are those which can directly fix and utilize the nitrogen of the air, a process for whose accomplishment man has to apply enormous stores of energy. Others can utilize carbon dioxide as their source of carbon without making use of chlorophyll. Still others can live without free oxygen, and obtain all

they want from chemical compounds. However, the great bulk of the food cycle of the world starts with the activities of green plants, and all animals, all fungi and most bacteria are in a very real sense dependent upon the green plants' chlorophyll.

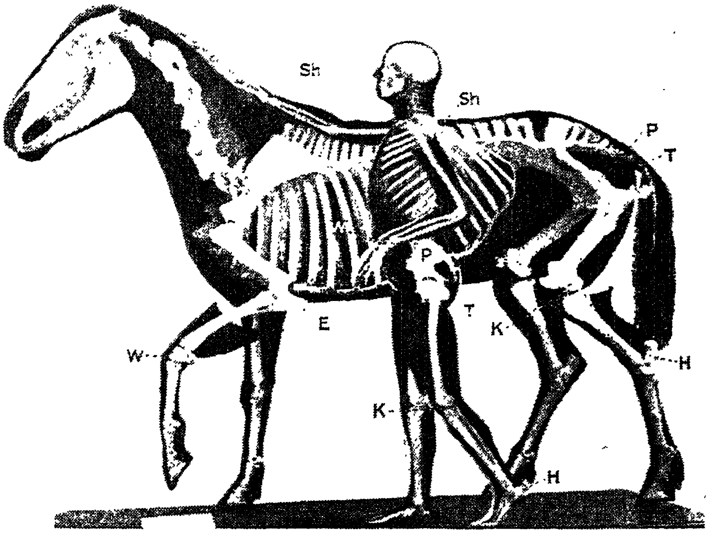
This is the basic distinction between animals and plants, and all the differences with which we are so familiar, between higher plants and higher animals, are purely secondary. The fact that green plants can obtain food from water and air, without special search, has led to their developing great feeding surfaces—such as the leaves and the roots—in air and water respectively. The fact that animals have to find their food ready-made has led to their developing mouths and stomachs to catch and hold the food, and limbs to move from place to place in search of more. The fact of locomotion has in its turn made necessary the development of sense organs and nervous system and brain. But all hinges on the first and most vital difference.

Even so, there are some types, among the simplest and smallest creatures, which share animal and plant characteristics, being able both to take in solid food like a typical animal, and to build up food from simple inorganic substances like a green plant. Such examples only show the impossibility of drawing hard and fast lines in Nature.

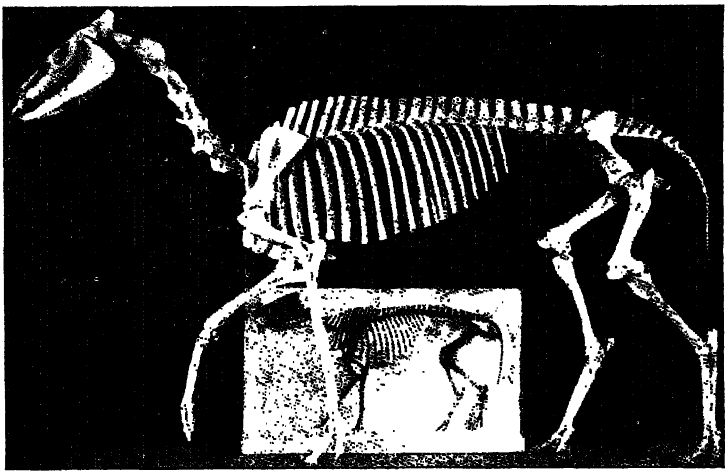
But these are all generalities, and in order to be able to deal properly with what is general, we must have a good acquaintance with the particular. The best way of doing this will be to take a single species of animal and describe its structure and working in broad outline. For our purpose any one of the higher animals would really serve, but on account of the ease with which it can be obtained, its convenient size, and the resemblance of its general structure and functions to those of man, we will take the frog as our introductory type, while man will be taken later to illustrate physiology in more detail.

The General Anatomy and Physiology of the Frog.

At first reading, the statement that frogs resemble men in any important degree may perhaps raise a smile. It is nevertheless true. We can recognize in the frog a great many parts that exist in ourselves, arranged moreover in the same way. A frog possesses a head, a trunk, and fore- and hind-limbs. The nostrils, eyes, ear drums and mouth are arranged in the same relative positions as in our head. If we look at

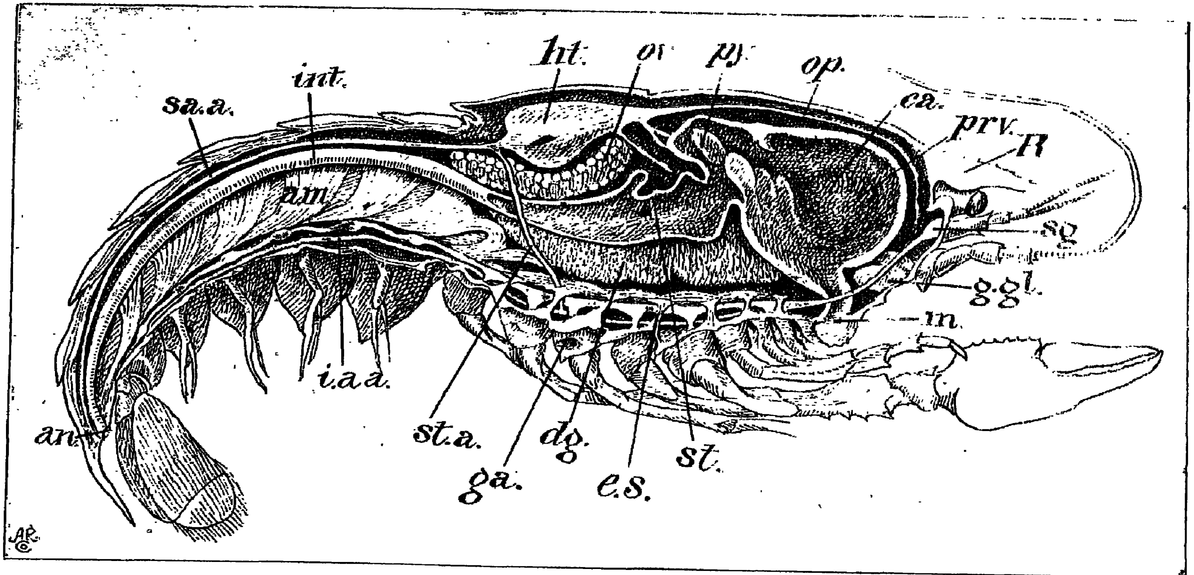


(i) Skeletons of man and horse, with outline of the bodies, to show the correspondence of general plan. E, elbow; H, heel; K, knee; P, pelvis; SH, shoulder-blade; T, tail vertebræ; W, wrist.



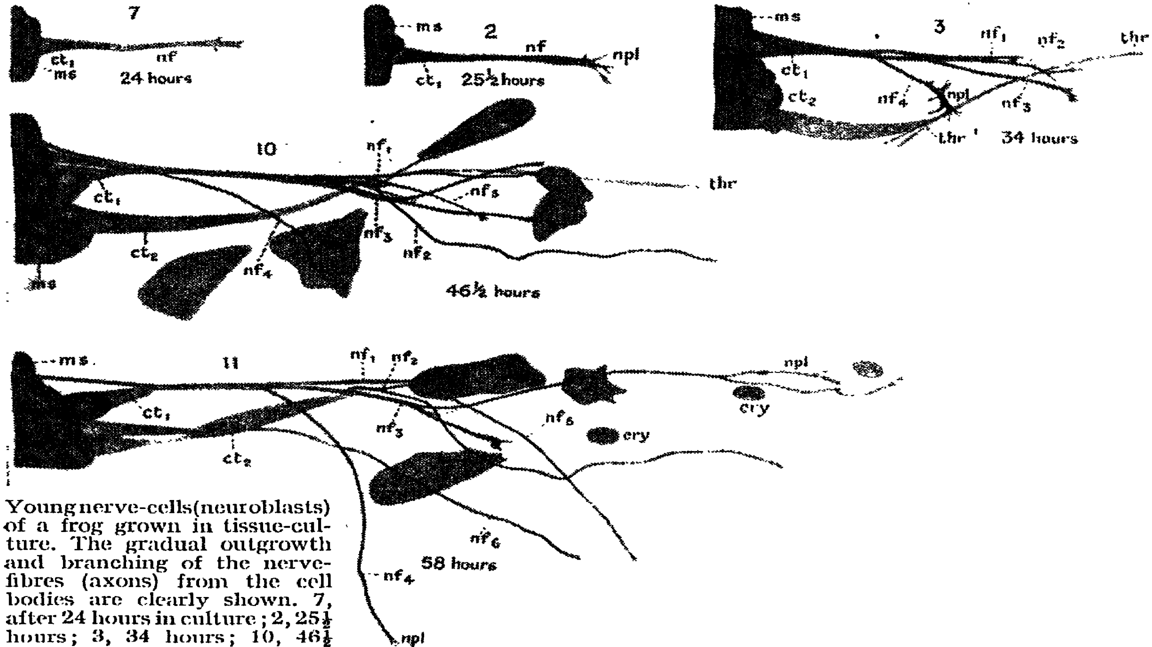
(ii) Photograph of skeletons of the small, ancestral horse Eohippus from the Eocene, with four toes on the fore-foot, and of the Miocene horse Hypohippus, with three toes on each foot, the central toe the largest. The later form shows considerable increase of size, and of relative length of limbs and neck.

PLATE 2



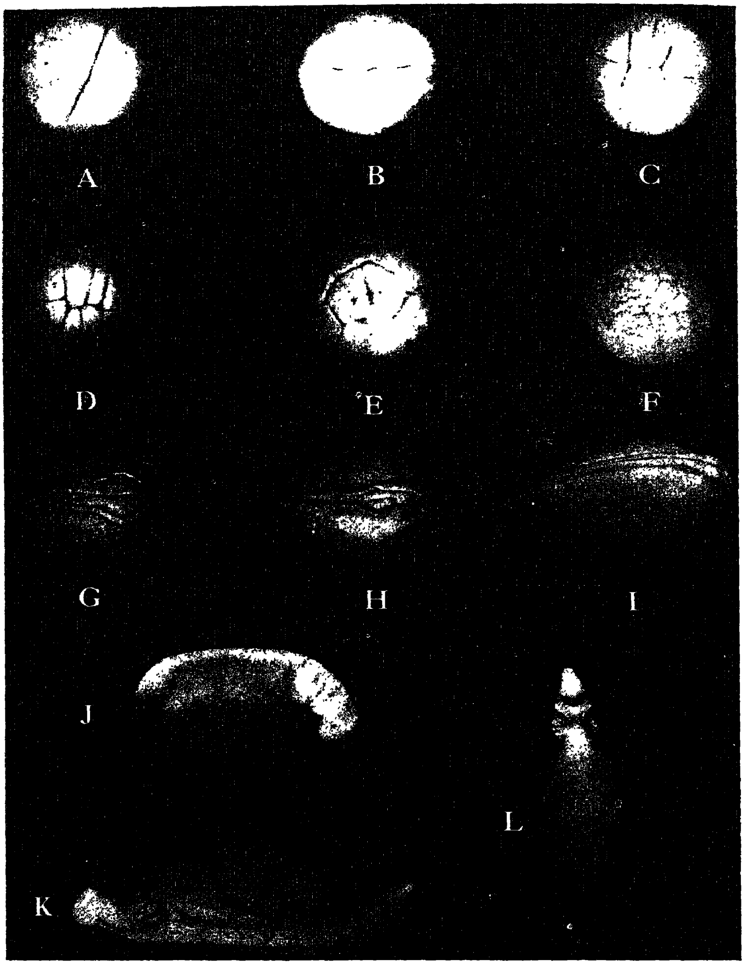
Diagrammatic dissection of a female crayfish (*Astacus fluviatilis*) from the right side. *am.*, flexor muscles of abdomen; *an.*, anus; *ca.*, "crab's eye" (calcareous mass on wall of gastric mill); *dg.*, tubules of digestive gland; *e.s.*, internal extensions of the skeleton overarching the nerve-cord; *ga.*, aperture of oviduct; *g.gl.*, excretory organ; *ht.*, heart, with aperture from surrounding blood space; *i.aa.*, ventral abdominal artery; *m.*, mouth; *op.*, artery to eyes; *ov.*, ovary; *prv.*, *py.*, gastric mill, with grinding teeth and straining apparatus; *R*, rostrum or sharp projection of head; *sa.a.*, dorsal abdominal artery; *sg.*, brain (supra-œsophageal ganglion); *st.a.*, mid-gut, with aperture of duct of digestive gland; *st.*, sternal artery. The ventral nerve-cord and ganglia are just over *i.aa.*

PLATE 3

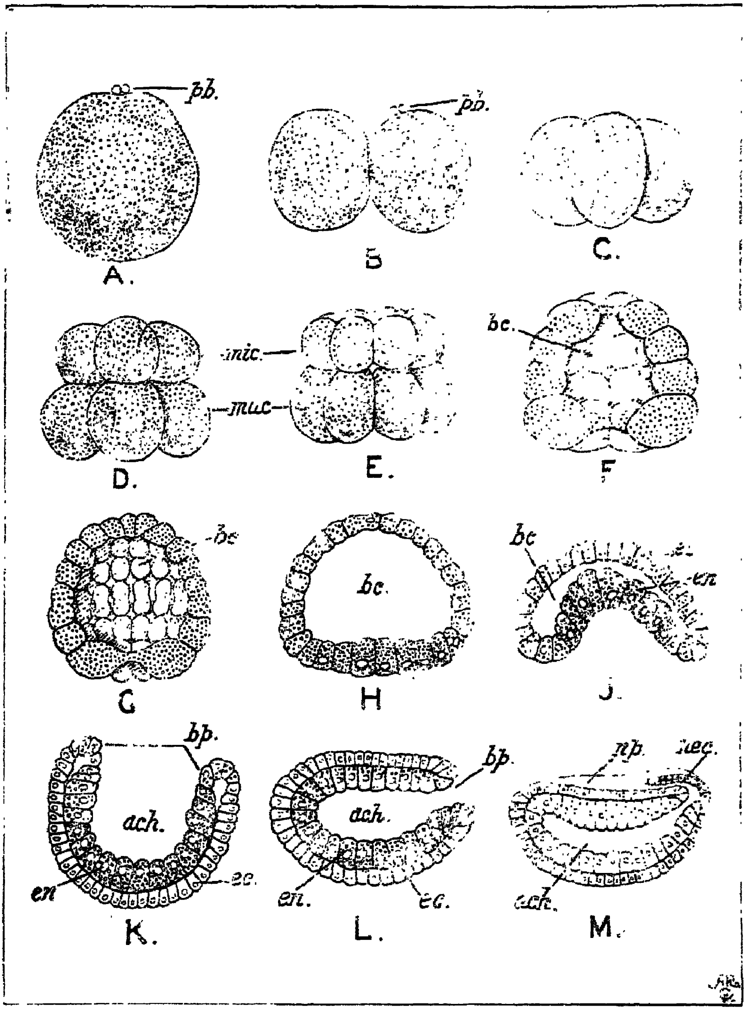


Young nerve-cells (neuroblasts) of a frog grown in tissue-culture. The gradual outgrowth and branching of the nerve-fibres (axons) from the cell bodies are clearly shown. 7, after 24 hours in culture; 2, 25½ hours; 3, 34 hours; 10, 46½ hours; 11, 58 hours; *nf*, nerve-fibre; *npl*, expanded tip with pseudopodia found on growing nerve-fibres. The longest nerve-fibre thus obtained was 1·15 mm., and it grew about 22 μ per hour.

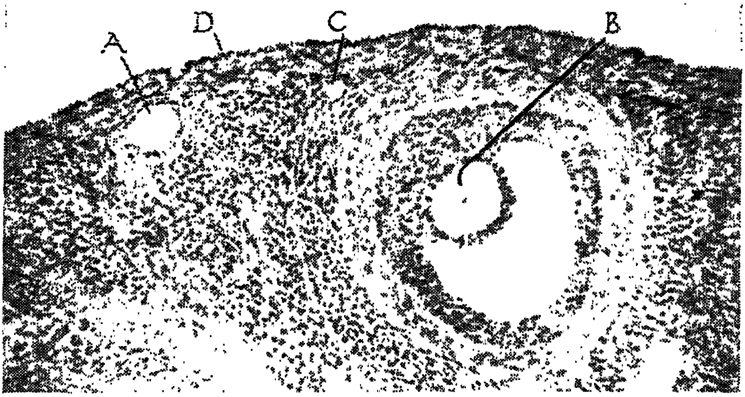
PLATE 4



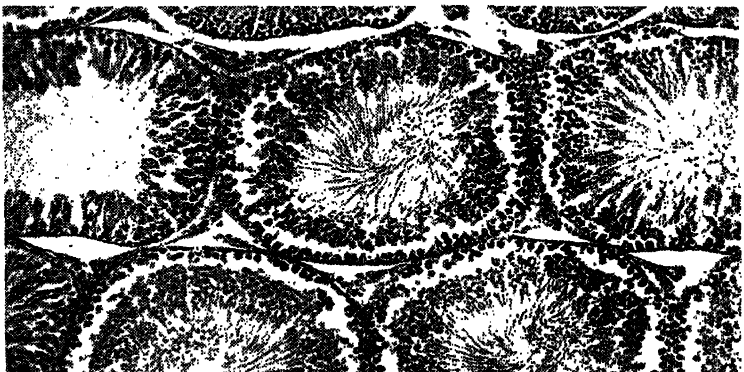
The early development of a tailed amphibian (Urodele). A, egg during the division into two cells; B, four-cell stage; C, beginning of sixteen-cell stage; D, E, later segmentation; F, blastula; G, neural folds have appeared (dorsal view, head to r.); H, neural folds closing; I, neural folds closed to form neural tube (oblique dorsal view, head to r.); J, from the r. side. Head and tail sharply marked off from yolk-mass. The gill-slits are seen in the neck region, the muscle segments on the fore-part of the trunk. K, later stage, from the r. side and upside-down. The tail has grown, and has developed ventral and dorsal fins. Fore- and hind-limb buds visible, yolk-mass relatively smaller; three tufted gills in the neck region. L, a similar stage, from below. In front of the gills in the middle line is the mouth, with the eye-rudiments just in front of it. (Smallwood, *Man, the Animal*, 1922.)



The early development of Amphioxus. A, fertilized egg, unsegmented; B, two-cell stage; C, four-cell stage; D, eight-cell stage; E, sixteen-cell stage; F, early blastula (thirty-two cells); G, late blastula; H, flattening of vegetative side of blastula; J, invagination to gastrula; K, partial gastrulation; L, late gastrula; M, beginning of formation of neural tube. *ach*, primitive gut; *bc*, blastocoel; *bp*, blastopore; *ec*, ectoderm; *en*, endoderm; *mac*, larger vegetative cells; *mic*, smaller animal cells; *np*, neural plate beginning to form neural tube; *pb*, polar bodies.

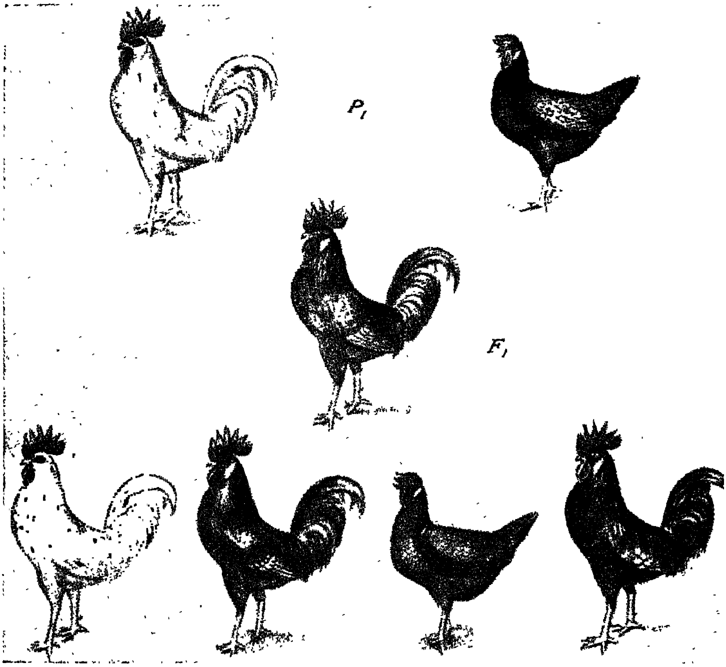


(i) Micro-photograph ($\times$ 150) of a section through the ovary of a mammal (cat). At A, a medium-sized oocyte (miniature ovum) surrounded by a follicle one cell layer thick. At B, a larger oocyte; its follicle has become several layers thick, and a cavity containing fluid has been formed in it. In the oocytes at A and B the large nucleus can be seen. At C, a very young oocyte. D, the edge of the ovary, bounded by a layer of germinal epithelium. (Photo by D. A. Kempson.)



(ii) Section across the testis of a mammal (rat). Note that it is composed of a series of little tubes, rounded in cross section. Their walls are composed of germ-cells (sperm-producing cells). Towards the centre may be seen ripe sperm, their tails in the hollow of the tubes, their heads still mostly attached to cells in the walls. Between the tubes may be seen small patches of interstitial tissue. (Photo by D. A. Kempson.)

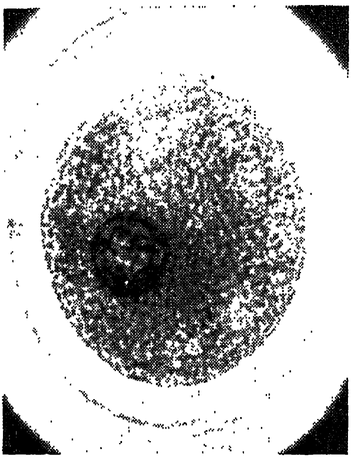
PLATE 7



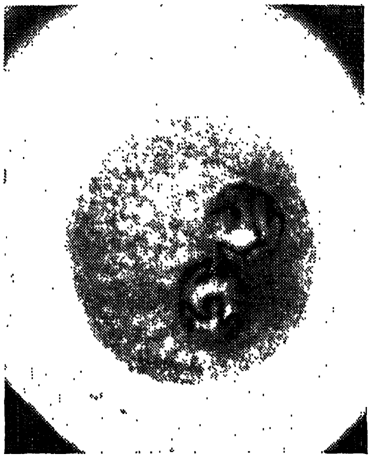
(i) To illustrate the results of crossing two pure-bred strains of fowls, splash white and black. P_1, the parents; F_1, the first hybrid generation, all individu of which are alike, of a bluish-black shade; F_2, the second hybrid generati derived by mating F_1 individuals together. Segregation is here shown, there be on the average one-quarter splashed-white like the splashed-white parent, c quarter black like the black parent, and one-half blue like the F_1.

(ii) A pair of identical twins (from Battle Creek, Mich., U.S.A.), who, although they were separated at three years of age and have since then always lived apart, have still retained an extremely close resemblance to each other, owing to their identical hereditary constitutions.

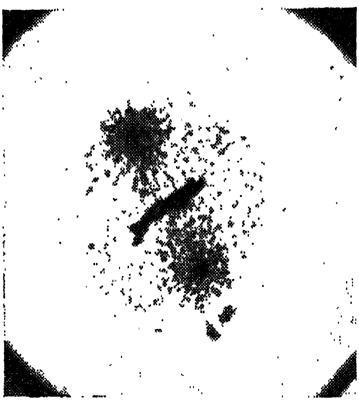
PLATE 8



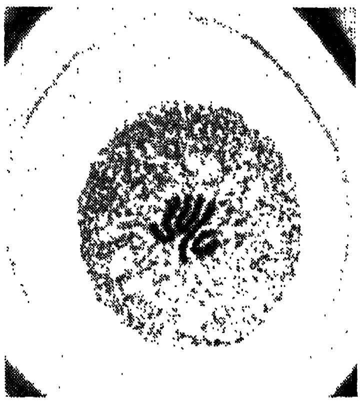
A



B



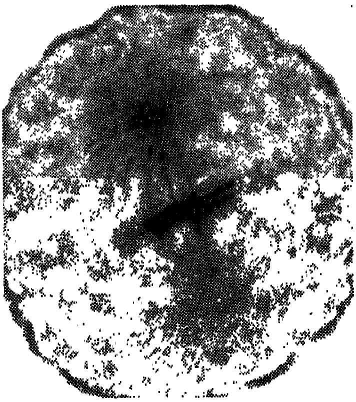
C



D

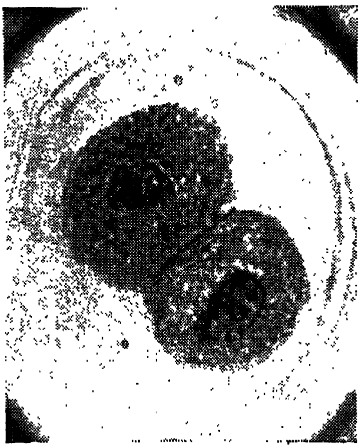
Mitosis, as illustrated by the fertilized egg of the round worm *Ascaris megalocephala*, from the intestine of the horse, which possesses two pairs of chromosomes. (From untouched micro-photographs by D. A. Kempson.) (*a*) Immature (unfertilized) egg with nucleus in "resting" phase. (*b*) Fertilization has just occurred. The nuclei of egg and sperm are approaching each other. The chromosomes have begun to appear (spireme stage). (*c*) Side view of the equatorial plate stage of the first division of the fertilized egg. The spindle is clearly seen with the centrosomes and asters at its two ends. The chromosomes have arranged themselves round its equator. (*d*) End view of the same stage. The four chromosomes are clearly visible.

PLATE 9

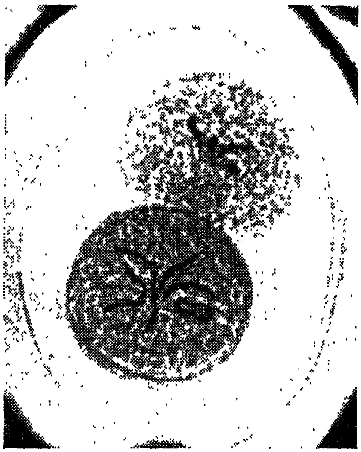


E

G



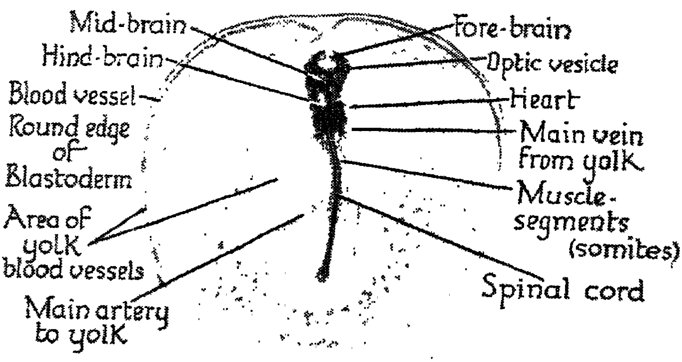
H



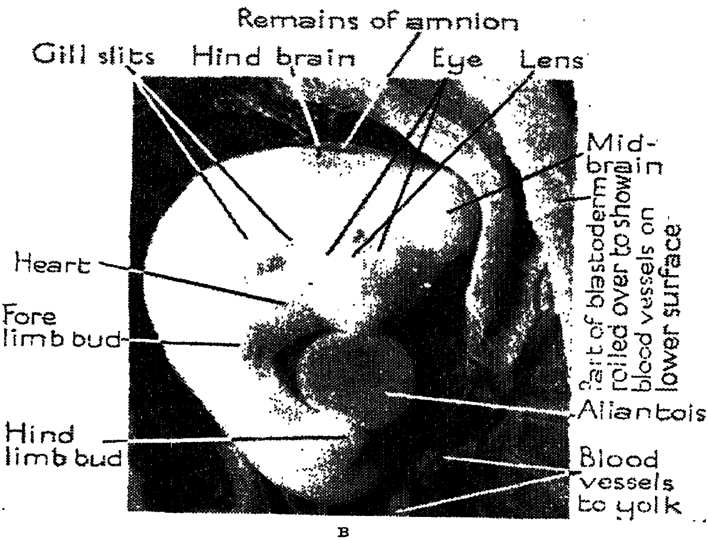
I

(*e*) Side view of a slightly later stage. The chromosomes have now split longitudinally. (*g*) "Telophase" stage. The two sets of chromosomes have moved apart to the two asters; the cell is deeply constricted. (*h*) Two-cell stage. The egg has completely divided into two cells; in either cell the chromosomes have joined up to form a "resting" nucleus. (*i*) Beginning of second cleavage. Mitosis has begun in both cells; one is so viewed as to show that four chromosomes have again appeared. In all figures the egg is lying in a space within a thick, transparent egg-membrane or shell. In (*c*) and (*g*) the two *polar bodies* are visible on the surface of the egg. The magnification for all except (*e*) is × 750. For (*e*), × 1,000.

PLATE 10



A



B

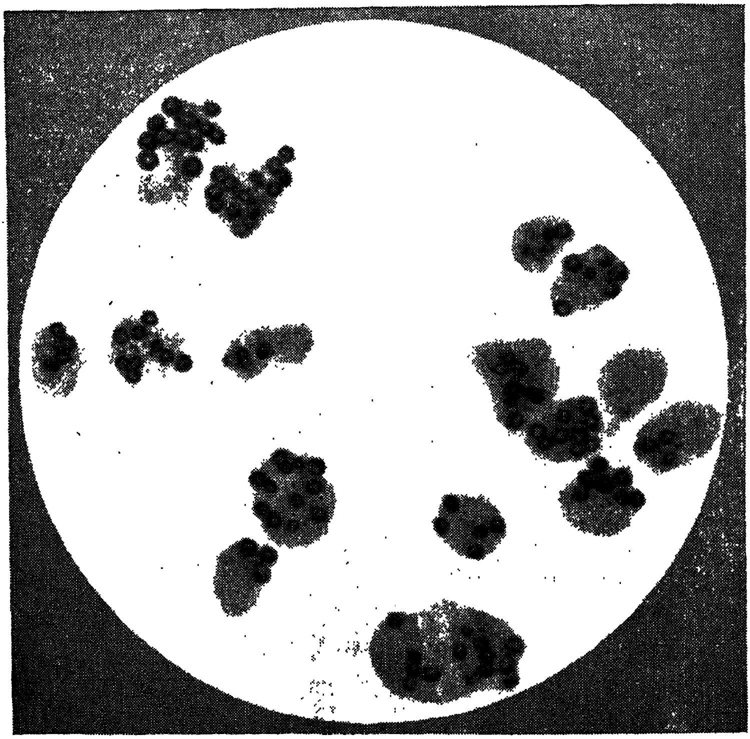
Embryo chicks of about thirty-six hours' and four days' incubation respectively. Both × 8. (A) has been stained and is photographed by transmitted light. In it about sixteen muscle segments have been formed, the three main divisions of the brain are visible, with the eye vesicles growing out from the fore-brain. The heart can be seen, together with a network of small blood-vessels over the yolk in the outer region of the blastoderm. (B) has not been stained and is photographed as an opaque object by reflected light. The amnion has been removed (small traces of it are left in the head region). The embryo rests on its left side, and the head has bent over. The limb buds, gill-slits, and allantois can be seen. The blastoderm in one place has rolled over, showing the way the blood-vessels run on its lower surface, next to the yolk. (Photos by D. A. Kempson.)

Right, an early human embryo, 7·1 mm. long, still enclosed in embryonic membranes. The yolk-sac is below, connected with the embryo by the umbilical stalk. The embryo lies inside the amnion, whose cavity it now nearly fills. The chorion is outside, and from part of it project tufts containing blood-vessels, which constitute the embryonic part of the placenta. The gill-slits are seen at the side of the neck, and the muscle segments are marked off by lines in the dorsal part of the trunk. The limbs are present, but no fingers or toes have yet been formed, although traces of the main joints are beginning to be visible.

Left, same embryo with its yolk-sac, removed from the embryonic membranes. The gill-slits, muscle segments and limbs are again well shown; in addition, a prominent tail is seen. (From photos by W. Chesterman, Department of Human Anatomy, Oxford.)

PLATE 12

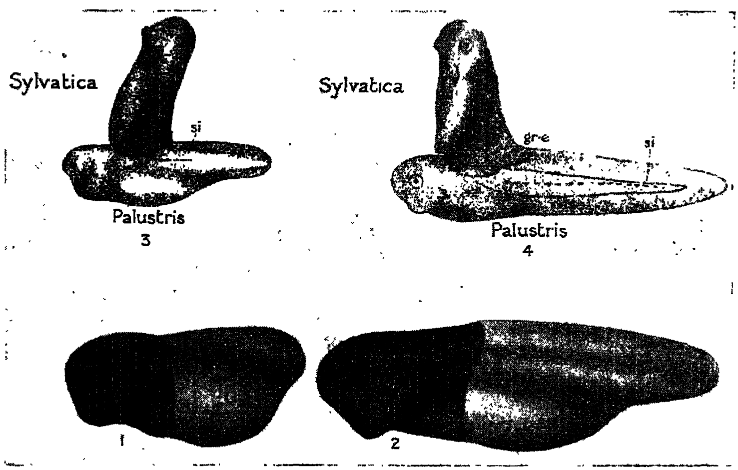
A



B

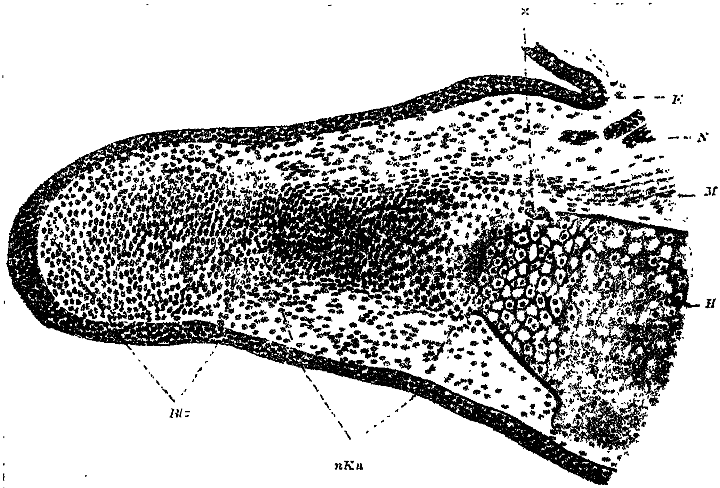
Two examples of Phagocytosis by human white blood cells. In (A) are seen one white and three red blood corpuscles. The white corpuscle has a large nucleus in three parts, and has ingested a number of *Micrococcus pyogenes aureus,* the common bacterium of boils, abscesses, etc. (B) is a micro-photograph showing white blood corpuscles which have ingested large numbers of foreign particles (sheep red blood corpuscles) with which they have been incubated.

(i) Two individuals of the same age from the same batch of frog's eggs. The one on the right is the control, and has metamorphosed normally into a frog. The one on the left had the whole rudiment of its thyroid removed, has not developed legs, has not metamorphosed, and has grown to a size much greater than that normally found in tadpoles of this species.

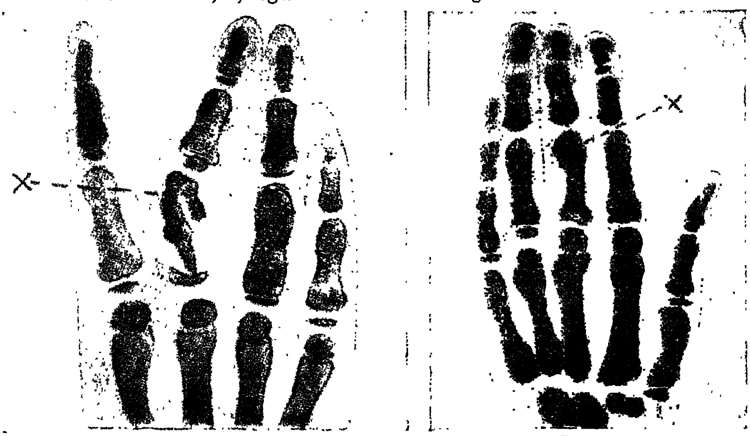


(ii) Two experiments in grafting in tadpoles. (1) The front half of an embryo of one American species of frog (*Rana sylvatica*) has been cut off and grafted on to the hind half of another, lighter-coloured species (*Rana palustris*). (2) The compound animal (chimæra) grows quite normally. The lateral line, which originates near the head, has grown down from the *sylvatica* component on to the *palustris* trunk. Compound individuals like this have been reared through metamorphosis. (3 and 4) The front part of a *sylvatica* embryo has been grafted on to the back of a *palustris* embryo : this combination also has continued development. The *sylvatica* lateral line (below *si*), on reaching the *palustris* component, has bent round into correct position.

Effects of thyroid insufficiency in man. On left, a cretinous child with grave thyroid deficiency, and consequent stunted growth and mental deficiency. In centre, the same child after some months' treatment with desiccated sheep thyroid. On right, the same child a year later, its parents having refused to continue the treatment. The symptoms have returned.

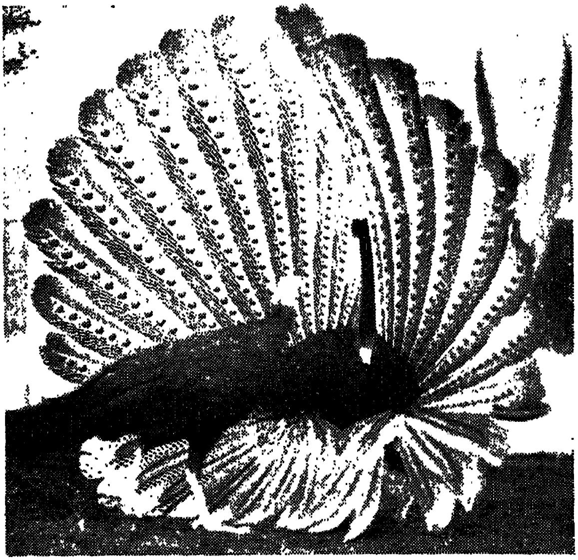


(i) A microscopic section (longitudinal) through a regenerating leg of a salamander larva. The cut was made at the level joining the line from *x* and the right-hand line from *nKn*. *Blz*, undifferentiated cells first produced at the cut surface; *E*, epidermis (with pigment below it only in non-regenerated part); *H*, cartilage of original humerus, with incipient bone formation at its edges; *M*, muscle; *N*, nerve; *nKn*, regenerated cartilage, differentiated out of cells like *Blz*; *x*, region where old cartilage is dedifferentiated.

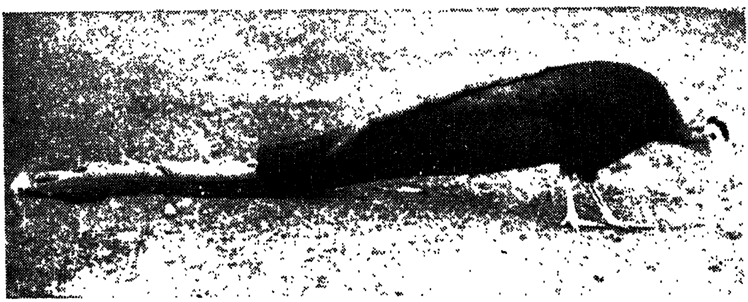


A B

(ii) X-ray photographs of the hand of a boy in whose third finger the basal joint became diseased; it was removed and a piece of healthy bone with its bone-forming membrane (periost) grafted in from another situation. (A) Six years old, immediately after the operation; the grafted piece of bone (x) is of an irregular shape. (B) Two years later (the position of the hand is reversed), the grafted piece has become moulded into a very good imitation of the original joint. (After Timann.)

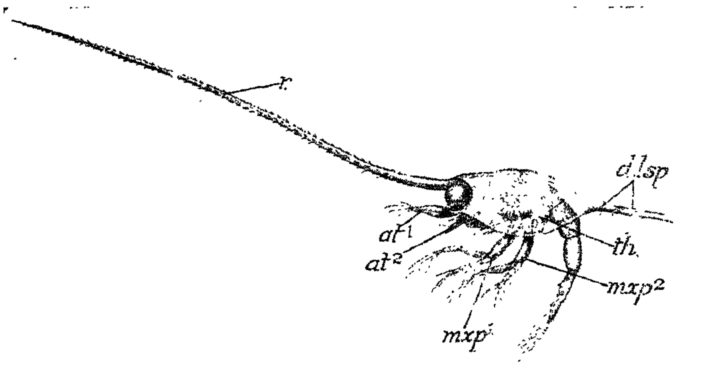


B

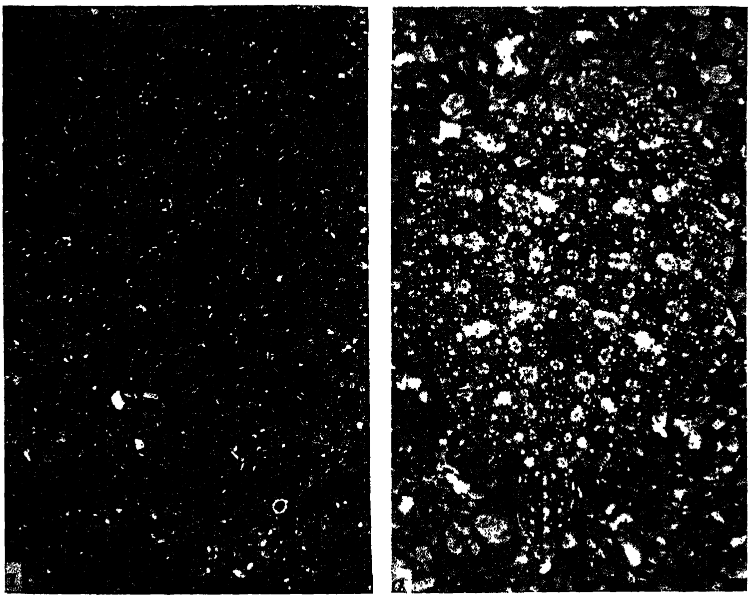


A

The courtship display of the Argus pheasant (*Argusianus argus*). (A) The cock Argus pheasant in ordinary attitude. (B) The hen interested in the display of the cock. The cock has spread his wings and thrown them upwards and forwards, displaying the beautifully shaped eye-spots on the wing quills. The tail meanwhile is jerked up and down; it is seen to the right. The head of the cock is almost concealed by the wings. However, just above the lower part of the left wing is seen a white spot, with a grey patch a little way to its right. The white spot is part of the beak, the grey patch part of the cheek. Between them there can just be distinguished the bird's left eye, looking out to see the effect of the display upon the hen. She is much smaller than the cock, and lacks the beautiful wing and tail plumes. (From photographs taken at the London Zoological Gardens by Mr. D. Seth Smith.)

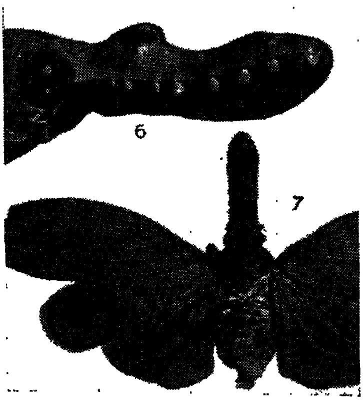


(i) Pelagic larva (zoæa) of a crab (*Porcellana*). Note the enormous anterior spine (rostrum), for increasing friction and preventing rapid sinking; also the abdomen not yet bent up under the thorax, thus recapitulating the ancestral condition. at^1, at^2, first and second antennæ; mxp^1, mxp^2, first and second maxillipeds (used for swimming at this stage, though for feeding in the adult); *th*, rudiments of the five pairs of legs. (MacBride, *Textbook of Embryology*, Volume I, 1914.)



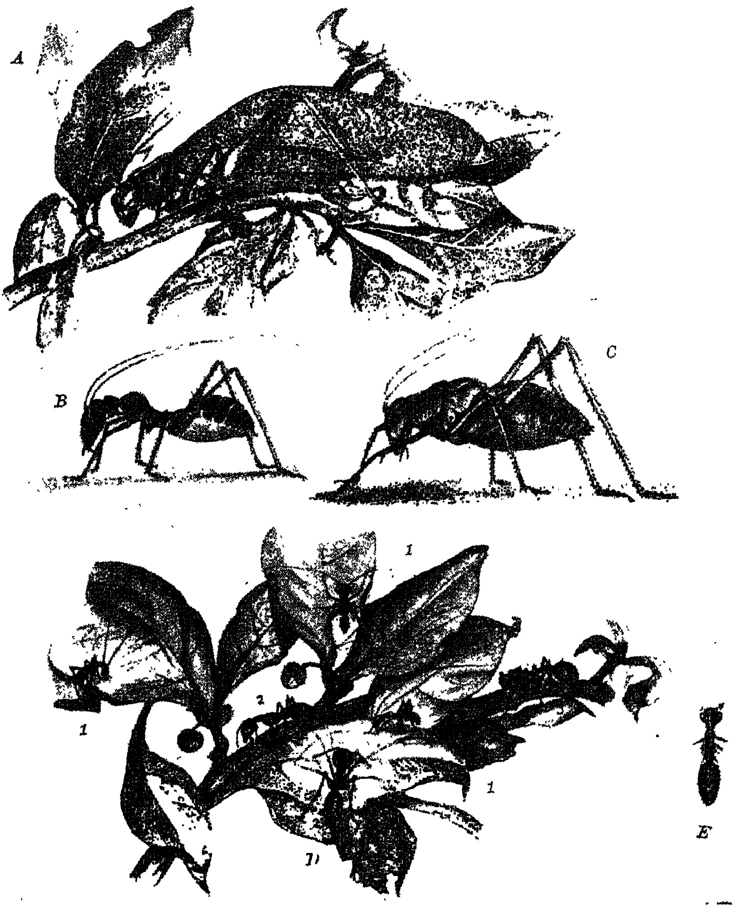
(ii) A small flat fish (*Rhomboidichthys*) on fine and coarse sandy gravel. The fish adapts itself to the background by changing its pattern.

(i) Protective resemblance. Four specimens of the Crustacean *Huenia proteus* on the seaweed *Halimeda*. The resemblance is striking, both in form and colour. (From Hesse-Doflein, *Tierbau und Tierleben*, II; Teubner, Leipzig and Berlin.)

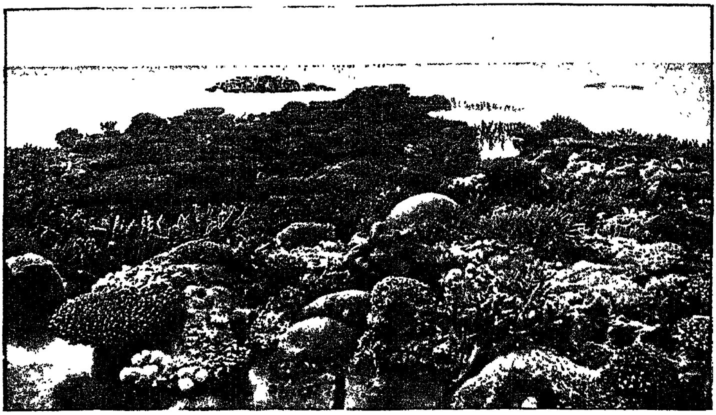


(ii) A lantern-bug (*Laternaria lucifera*) with extraordinary resemblance of the expanded front region of the head to a small crocodile's head. Many lantern-bugs have this anterior prolongation of the head. In this case the resemblance to a crocodile has been brought about by black patches simulating nostril and eye (with white patch simulating reflection of light), the "eye" on a projection as in a crocodile. The line of the jaws is clearly indicated, and whitish triangles, which actually protrude somewhat from the surface, closely simulate teeth. The insect's own eye is seen behind the angle of the apparent "jaw." It has plausibly been suggested that this resemblance is of service to the insect in scaring away small insectivorous birds and mammals. No other possible function has been assigned to it; and in any case the detailed resemblance is very remarkable. (Photograph by A. Robinson.)

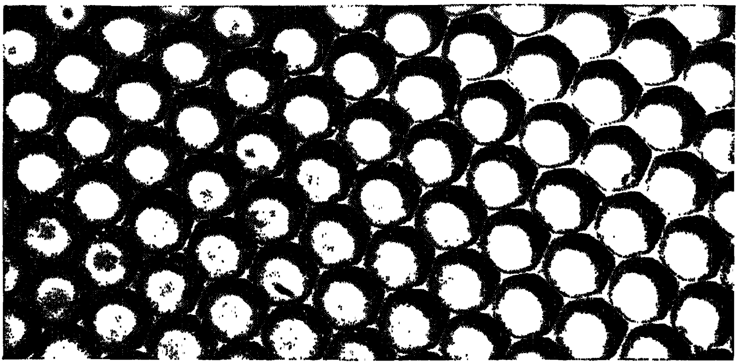
PLATE 19



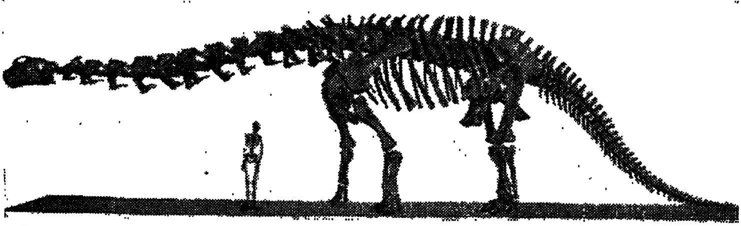
Mimicry and protective resemblance in the East African grasshopper *Eurycorpha*. When full grown (*A*) the animal is large and green, and readily escapes detection among the leaves on which it lives. When young (*B*) it closely resembles an ant, and the long antennæ are so thin as to be visible with difficulty in nature; it even possesses two pale patches on the sides of its abdomen (*E*), which give it the appearance of possessing a "waist" like an ant. (*D*) shows three young larvæ (1) with specimens of two kinds of ants (2 and 3). In this stage, the young grasshopper's behaviour is like that of an ant, and it runs about among the ants in a restless way. The full-grown animal, on the contrary, spends most of its time without moving. While growing up (*C*) the animal is intermediate; it tries to escape its enemies by hiding or by "shamming dead." (From Hesse-Doflein, *Tierbau und Tierleben*, II; Teubner, Leipzig and Berlin.)



(i) A view at low water on the Great Barrier Reef of Australia, showing various kinds of corals, each of them a colony of many thousands of polyps. (After Saville Kent.) (From Hesse-Doflein, *Tierbau und Tierleben*, II; Teubner, Leipzig and Berlin.)



(ii) Micro-photograph of part of the surface of an insect's eye. The large number of separate facets, each with its own cornea, is clearly shown.



(iii) Skeletons of the extinct Dinosaur Diplodocus and of a man. The brain of Diplodocus was a good deal smaller than the enlargement in the spinal cord opposite the hind limb.

The hind leg bones of Diplodocus, in situ. Bone-cabin Quarry, Medicine Bow, Wyoming. (Reproduced by permission of the American Museum of Natural History.)

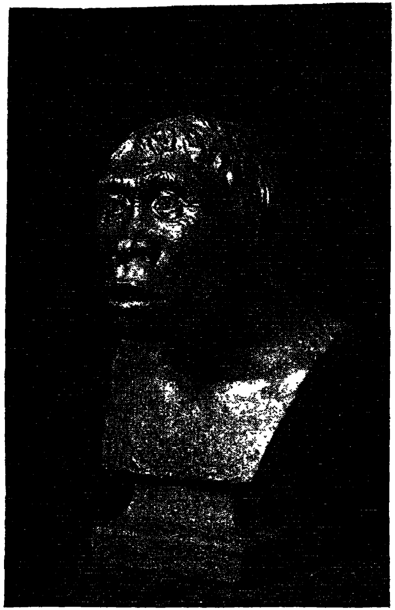
PLATE 22

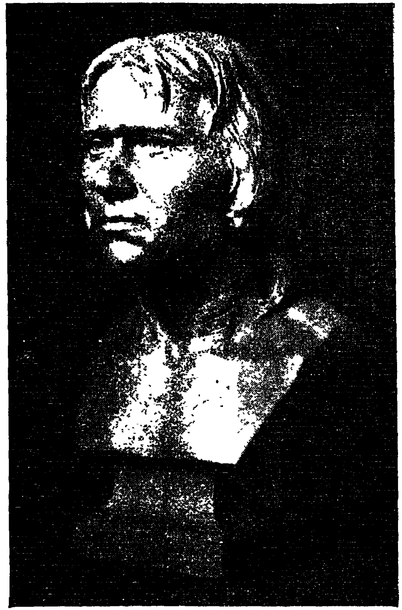
An enormous herd of marine iguanas (*Amblyrhynchus*) on the Galapagos Islands. These animals may exceed four feet in length. The photograph illustrates the size and abundance which reptiles may attain in tropical regions. Note also the scarlet rock-crab (*Grapsus*), a semi-terrestrial crustacean, in the foreground. (From *Galapagos*, by William Beebe. Photograph by R. H. Beck. Reproduced by permission of the publishers, G. P. Putnam's Sons.)

PLATE 23

Photograph of four young chimpanzees (aged 2 to 6 years) eating at table in the London Zoological Gardens. As a result of six months' training they not only sit up to their meals and have as good table manners as an average child, neither spilling their food and drink nor snatching, but have learnt to be polite and to offer food to their companions before helping themselves. They differ considerably in temperament and intelligence, the eldest (second from left) being the most intelligent, the one on the right being the least clever, but having a very affectionate disposition; he always helps the youngest down from her chair. (Reproduced from a photograph by F. W. Bond, by permission of the Zoological Society of London.)

PLATE 24





Restorations (by Professor J. H. McGregor) of three stages in the evolution of man. On left, *Pithecanthropus erectus*, intermediate in brain size and protrusion of jaws between man and apes. In centre, Neanderthal man (*Homo neanderthalensis*), the extinct species of man found in Europe in early Palæolithic times. This species still retains primitive characters such as low cranium, very large brow ridges, heavy teeth, poorly developed chin. On right, Cro-magnon man, a race of *Homo sapiens* or modern man which succeeded Neanderthal man in Europe in the late Palæolithic period.

the skeletons of man and frog, we shall find that both possess a skull, a backbone consisting of separate jointed pieces or vertebræ, the same type of limb bones, the same kind of teeth. If we dissect them, we shall in both discover red blood, a heart in the front of the trunk and on the ventral surface, a liver, a pair of kidneys, a spleen, a nerve cord within the backbone, and a great many other organs which have a family likeness to each other, and are to be found in similar positions in the bodies of the two organisms. The same plan is also found in the horse (Plate 1 (i) and Figs. 2, 5; for Plates *see* p. 128).

But if we had chosen a crayfish, say, as our type, these correspondences would not have been there. A crayfish possesses not two but nineteen pairs of limbs. It has no backbone, but grows its skeleton on the outside. It has a heart, but it is in the centre of the body, and towards the back or dorsal side; its blood is nearly colourless; it has no nostrils or ear-drums; no spleen; the nerve cord runs down its ventral side instead of along its back; its kidneys are in its head—in fact, it is difficult to find any point in which its plan of structure closely resembles that of man (Plate 2).

We shall come back to this question of the resemblances and differences between animals. Now we must return to the frog, and ask ourselves what it does and how it does it.

Like other animals, the frog eats; it breathes; it must get rid of waste; it must move in order to procure its food or to escape its enemies or to find its mate; changes in the outer world affect it; there must be some means by which the parts of its body can be made to act together as a whole, instead of merely as a number of separate parts; and finally, it reproduces its kind.

Why does the frog, or indeed any other animal, require food? It requires it for two main reasons. First, the frog is doing physical work every time it moves; to do work it needs some source of energy; and, as a matter of fact, it obtains this energy by the oxidation or slow combustion of some of the substances contained in its food. Secondly, the substance out of which it is made is all the time slowly wearing out or breaking down, and needs to be repaired continually by other substances out of the food. The living machine thus burns part of its food for fuel, and uses other parts for repairs.

The frog feeds on worms, small snails and slugs, insects, and other

small animals. It seizes them with its tongue, which is sticky and attached at the front instead of at the back, and can be suddenly shot out of the mouth. Once in the mouth, the prey is held not only by the teeth, which are small, all alike in shape, and only to be found on the upper side of the mouth,* but also by the eyeballs, which, unlike our own, can be brought right down into the cavity of the mouth. At the back of the mouth the prey is forced into the opening

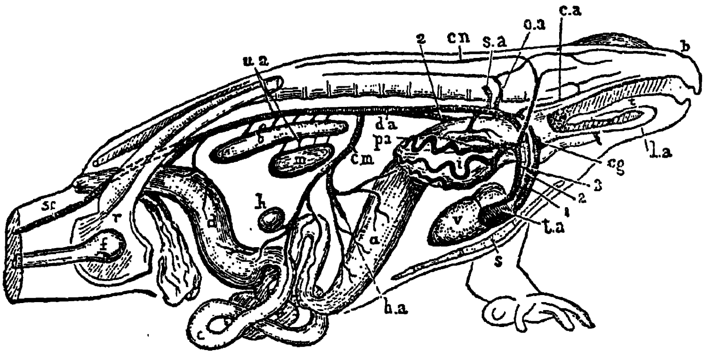


FIG. 2. General anatomy and arteries of a male frog (veins omitted). *a*, stomach; *b*, nostril; *c*, small intestine; *c.m*, artery to gut; *c.n*, artery to skin; *d*, large intestine (rectum); *d.a*, dorsal aorta; *f*, thigh bone (femur); *h*, spleen; *h.a*, artery to liver; *i*, lung; *m*, testis; *o*, kidney; *p.a*, artery to lung; *r*, hip girdle; *s*, breast bone; *s.a*, artery to fore-limb; *s.c*, artery to hind-limb; *t*, tongue; *t.a*, truncus; *v*, ventricle; 1, 2, and 3, main arteries (arterial arches), springing from truncus—1, to head; 2, to limbs, trunk, and main organs; 3, to lungs and skin. (Marshall, *The Frog*, 1923.)

of a narrow tube, the gullet, which leads down into the sac-like stomach. Once any solid object is inside the gullet, this contracts automatically in a series of waves, driving the object downwards and into the stomach. Out of the far end of the stomach opens a coiled narrow tube, the small intestine; but the opening can be closed by a ring of muscle called a sphincter, and as a matter of fact the prey is kept in the closed stomach for some time. During this time it is exposed to the action of a juice, the gastric juice, which is manufactured by the walls of the stomach, and as a result it becomes largely dissolved.

* It possesses teeth not only on the upper jaw, but also on the roof of the mouth.

When it is reduced to a pulpy broth, it is passed on to the intestine.

Into the beginning of the intestine there opens a very small tube or duct. This is the bile duct, which leads from the liver, a very large brownish organ divided into several lobes; the bile, which is produced by the liver, is a green fluid, and is stored until wanted in a round vessel, the gall bladder, connected with the bile duct. From the pancreas, a small pinkish-white organ, a number of still smaller tubes run to open into the bile duct. The bile and pancreatic juice, together with a juice derived from the intestine itself, complete the work begun in the stomach, until finally all of the food that is available for the use of the body is dissolved. It can now be passed through the living wall of the intestine into the blood and so distributed to the rest of the body.

The process of rendering the food soluble is what we call *digestion.* This is completed in the first part of the small intestine, while *absorption* takes place in the remaining parts. When all the absorption that is possible has taken place, there still remains some residue, indigestible and useless to the animal. This is called the fæces;* it passes from the small intestine into the broader and shorter large intestine or rectum; here it is consolidated into pellets, and is eventually passed out between the frog's legs at the opening of the cloaca, from the Latin word for a sewer.

There is thus a tube, the digestive tube, running from mouth to cloaca. Its cavity is open to the exterior at both ends, and so is, in a certain sense, not inside the frog at all. Digestion is simply the process of turning the food into a condition when it can be passed, by absorption, into the real interior of the body. It would be perfectly possible for an organism to absorb food over the whole surface of its body, and, as we shall see later, some animals do so. But in a creature like the frog it is obviously important that the part of it which is directly exposed to the outer world should act as a protective covering. Accordingly we have the external surface covered by the protecting skin, while the duties of digestion and absorption, which demand more delicate tissues, are carried out by an internal surface, the lining of the gut.

The stomach and intestine lie in a space, the general body cavity or

* Often popularly miscalled *excreta.*

coelom; they are kept in place within it by a delicate fold of membrane, the mesentery, which connects them with the dorsal side of the body cavity (Fig. 3). In this membrane may be seen a large number of red tubes—blood-vessels conveying the red stream of blood, always in the same direction in any one tube. On the gut itself a meshwork of very small vessels can be seen; as a matter of fact their

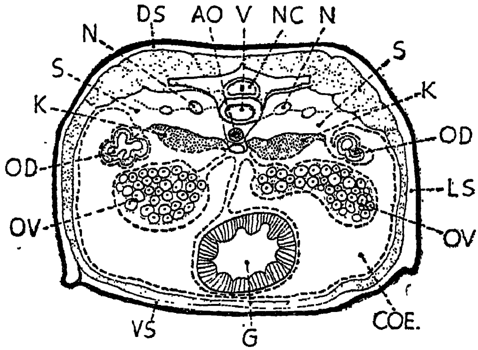


FIG. 3. Section across the hinder end of the trunk in a female frog. The abdominal organs (*G*, gut; *ov*, ovary; *od*, oviduct) protruded into the main body-cavity or coelom (*Coe*), which contains a colourless fluid. The lining of the coelom (or peritoneum) is dotted, the gut is suspended in the coelom by the mesentery, a double fold of peritoneum *K*, the kidneys, protruding slightly into the coelom. *S*, *Ds*, *Ls*, *Vs*, lymph spaces; *Ao*, aorta; *V*, a vertebra, in which is running the nerve cord; *NC*, *N*, spinal nerves. The body-wall is composed of skin, lymph-space, muscles (shaded), and outer lining of coelom.

smallest microscopic branches, or capillaries as they are called, come into close connexion with the lining of the digestive tube, and the dissolved food substances are passed through their walls into the blood. The small branches can be seen to unite into larger, and these into larger still, until finally the whole of the blood from the gut is seen to pass into the liver by a single vessel (Fig. 23).

Before we pursue the fate of the blood in the liver, we must consider the general plan and working of the blood system. The web of a frog's foot or the tail of a tadpole is transparent enough for us to see its blood-vessels under the microscope. We see solid particles, the blood corpuscles, hurried along within these various sized tubes in a stream whose motion is always in one direction, and takes place by jerks. The blood-vessels are branched, and in some of them the blood passes from large trunks to smaller and smaller branches, in others from the small branches to the main trunks. The former sort of vessel is generally called an artery, the latter a vein. If a frog is dissected, most of the large trunks are found to end in the heart; if this is opened, it is found to be nothing more nor less than a hollow bag of muscle, divided into several chambers. As we shall see, it is so constructed that when the muscles contract, or in other words the heart beats, the blood is driven through it, always in the same direction, owing to the arrangement of valves within it. From what we said above, it is clear that the blood leaving the heart will pass into the main arteries, and that blood will be pushed in from the main veins to take its place. The blood moves in jerks because of the successive beats of the heart, and the net result of the working of the system is that blood is continually circulating from the capillaries to the heart and back again. This simple fact of the blood's circulation, although at the bottom of any real knowledge of physiology, was not discovered until the early seventeenth century, by William Harvey (Figs. 23, 24).

There are three pairs of arteries leaving the frog's heart. One divides into branches supplying the mouth, head, and brain. The next pair is the largest; the two members of the pair unite to a common trunk running along the back, and called the dorsal aorta. This pair sends branches to both limbs, to the digestive system and all other internal organs, and to the muscles of the body. The third pair sends one branch to the lungs and another to the skin. The three pairs between them supply blood from the heart directly or indirectly to every organ of the body (Fig. 2).

In the organs, the smallest branches of the arteries divide into capillaries and the blood is driven on from these into the small veins The system of veins is more complicated than that of the arteries. The blood from the head, fore-limbs, skin, and lungs passes directly to the

heart; but that from other parts travels a more complicated route. The blood from the capillaries of the digestive system, as we saw, passes into the liver in a large vein. In the liver, this branches and forms capillaries again, new veins are once more formed from these, and the blood only reaches the heart after having passed through two sets of capillaries instead of one. Such a vein is called *portal*; and we have thus the portal vein of the liver. There is also in the frog (but not in man) a portal vein of the kidneys, which leads most of the blood from the capillaries of the hind limbs to a second set of capillaries in the kidneys.

The living tissues of every part of the body are thus in contact with capillary blood-vessels, and these have such thin walls that soluble substances can diffuse through them from the slow-moving blood in them to the tissues or from the tissues to the blood. Since the capillaries are all part of the single blood system, and the blood is always in circulation, it follows that substances from any part of the body can be transported to any other part. The blood system is thus, among other things, the body's system of distribution and exchange. It plays roughly the same part in the body of a frog or a man as is played in a modern nation by the traffic of railways, roads and canals, the markets and retail tradesmen, the last-named being represented by the capillaries.

What is it that the blood distributes? In the first place, food. The dissolved food from the gut is taken to the liver; this acts as a sort of warehouse and refinery. Some surplus food is stored there to be distributed gradually as needed, and other food substances are chemically changed by its action.

The next substance to be distributed is oxygen. It is obvious that energy is needed for carrying out movements, and as a matter of fact it is provided by the combination of oxygen with substances in the muscles; the more muscular work is done, the more oxygen is needed; the brain, too, is very sensitive to lack of oxygen; indeed we can say that the general processes of life in higher animals are only possible as a result of steady oxidation.

Oxygen is a gas. For it to pass into the blood there is needed a moist membrane, very thin, with oxygen on the one side and capillaries on the other. Since oxygen exists in the air, it would be possible for the

skin to be utilized as such a membrane; and this does actually happen in the frog. Its skin is very richly supplied with blood-vessels, and is always moist. As a result, frogs can only live in damp places. Higher organisms, such as ourselves, have a stronger skin, and one which is dry. They can, therefore, live in more varied surroundings, but can no longer use their skin for absorbing oxygen.

The frog, however, does not rely entirely on its skin, and it also possesses lungs, which can best be thought of as an internal surface specially designed for exchange of gases between blood and air. The lungs in both frog and man are a pair of spongy thin-walled bags divided up into a great number of compartments (and so providing a great deal of surface) in whose walls run very many blood-vessels. They are put into communication with the air by means of a tube, the wind-pipe or trachea, which opens into the back of the mouth cavity just in front of the gullet. In ourselves, air is sucked into and forced out of the lungs mainly by the movements of the chest and diaphragm, to whose walls the lungs are attached. But in the frog, air is sucked into the mouth through the nostrils, and then forced down into the lungs by contraction of the muscles of the throat, the nostrils being at the same time closed; it is driven out again by the elasticity of the lungs themselves. The frog has no diaphragm. The difference between our method and the frog's is like that between a suction pump and a force pump.

The oxygen passes into the blood system through lungs and skin, and, like the food, is distributed by the circulating blood to all parts of the body. Here it enters into combination with various constituents of the living substance, and, as a final result of these chemical processes, waste products are produced, which damage the organism if they accumulate, and must be got rid of. The most important of these end products of life's activity are carbon dioxide (CO_2), water (H_2O), and urea (N_2H_4CO); and the process of ridding the body of such substances is called *excretion*. Carbon dioxide is a gas, and its excretion can and does take place through the same membranes, of lungs and skin, which serve for the intake of oxygen. Urea, however, and any surplus salts, are not gaseous and so can best be excreted in solution.*

* They could also be removed from any share in the processes of life by being rendered insoluble. This occurs, for example, in lobsters and crabs, where some waste substances are deposited in the shell, and got rid of at moulting.

The chief organs which remove substances from the blood in solution are the kidneys. In the frog, these are found at the back of the coelom (Figs. 2, 3). They consist of a great number of microscopic tubes, twisted together, and richly supplied with blood. The tubes eventually all open into a large draining tube, or duct, which runs backward and opens into the cloaca. Surplus urea and salts, together with water, are taken up from the blood by the little tubes, and the resulting fluid or urine is drained out along the duct (Fig. 29).

Just opposite the openings of the ducts into the cloaca is another opening, that of the bladder, which is thin walled and muscular, and lies on the front of the large intestine. This is simply used to store the urine until a considerable amount has accumulated, when it is passed out of the cloaca.

Finally, not all the surplus water is excreted by the kidneys; some is got rid of in the form of water vapour by lungs and skin.

The whole of the chemical processes going on in an organism are known collectively as its metabolism. This consists partly of the building up of the soluble food materials into very complex colloid molecules, of which the living framework consists, partly in the breakdown and wastage of this framework, partly in the breakdown of the simpler substances which act as fuel for energy production.

If we now turn back for a moment to the blood system, and consider its detailed arrangement, we shall see that this can be understood in relation to metabolism. It will be easier to illustrate this from the blood system of man, which is in some ways both simpler and more efficient. Here the heart consists of two separate halves, a right and a left, each consisting of a thin-walled chamber or auricle opening into a thicker-walled ventricle. The veins enter the auricles, the arteries leave the ventricles; and there exist flaps of membrane which act as valves and only allow the blood to pass in the one direction. The only veins which enter the left auricle come from the lungs; they therefore contain blood rich in oxygen and poor in carbon dioxide. In this condition blood is called arterial. From the left auricle it passes on into the left ventricle, and thence into the main artery or aorta, whose branches carry blood to all the organs with the single exception of the lungs. In the capillaries of the organs, the living tissues take the oxygen they need from the blood, and discharge into it the carbon

dioxide they have produced. The resultant blood, poor in oxygen but rich in carbon dioxide and other waste products, and called venous blood, is collected in the veins, and is sucked into the right auricle. Thence it is pumped into the right ventricle, and so through an artery to the lungs. The way in which the system of pump and tubes is constructed thus ensures that all blood which has given away oxygen to the organs of the body shall go to the lungs, to be charged again with oxygen and to be rid of carbon dioxide, before going out once more to any of the other organs. The portal vein takes all the blood from the digestive system to the liver so that the surplus food materials may be there dealt with at once before going to the rest of the tissues; the liver is thus in one respect like a central storehouse from which certain foodstuffs are rationed to the rest of the body as required (Fig. 23).

In the frog the plan of the blood system is slightly different. Both auricles open into one single ventricle, so that some mixing of venous and arterial blood takes place. From the ventricle springs a tubular part of the heart, or *truncus*, not found in man. The position of the aperture from ventricle to truncus, and the valves inside the truncus, are so arranged, however, that the most arterial blood passes into the artery leading to the head, the mixed blood into that supplying the limbs and body, the most venous blood into that leading to the lungs. Thus the brain gets the blood richest in oxygen, and most, but not all, of the venous blood is taken to the lungs before again going to body or head.

The blood system, however, is not only concerned with transport. Organisms are faced with the problem of co-ordination: and the blood system provides one method of dealing with this. The problem is this: given a number of organs, such as heart, lungs, limbs, stomach, kidneys, brain—how to ensure that they shall work together for the good of the organism, and not simply pursue their own activities independently of each other—how, in other words, to convert a mob into an army.

The way in which the pancreas is made to secrete its digestive juice at the right time, and only at the right time, will provide us with a good example of co-ordination through the blood stream. The pancreas is usually inactive; but the passage of food from the stomach into the intestine is known to be followed by a secretion of pancreatic

juice which is poured down the duct to help digest the food. How is this done? When the food passes into the intestine, it stimulates the intestine chemically, causing it to secrete a special substance from its lining; this passes into the blood, circulates through the whole body, but, though it exerts no effect on most organs, stimulates the pancreas (and probably the liver) to activity. This substance is called "secretin." It can be artificially extracted from the lining of the intestine and will then, if injected, cause the pancreas to secrete. Such "chemical messengers" are called *hormones*, and the blood provides the channel by which they exert their chemical co-ordination between parts of the body. As they are secreted into the blood, and not down a duct on to some free surface, they are included under the term *internal secretions*.

Other internal secretions regulate growth and metabolism, prevent one organ from growing disproportionately to the rest, or have a say in the rate at which the various chemical processes of life shall work. A substance secreted by the pituitary, for instance, which is a small gland at the base of the brain, influences the growth of bone. If too much of it is present in youth the bones grow excessively, and giants are the result. Another substance secreted by the same gland causes frogs to become darker in colour. The thyroid gland is situated in the neck region of vertebrates. Its secretion influences the rate at which their metabolism goes on; with most mammals, too much makes them nervous and excitable, too little leaves them sluggish. The adrenals, the parathyroids, the pancreas, the reproductive organs, and probably other organs also produce internal secretions.

Finally, the blood helps in the defence of the body. If proteins which are not normally found in a certain organism are injected into it, they are precipitated or broken down into simpler substances. Not only that, but if they are injected a second time after a proper interval, they can be destroyed more rapidly and in greater quantity. Bacteria, many of which, if they could live in the tissues or the blood, would give rise to diseases, contain such foreign proteins; and in nature it is chiefly bacteria which are thus destroyed if they obtain an entrance into the tissues. Familiar examples of the utilization of this property are vaccination, preventive inoculation for typhoid, and the antitoxin treatment of diphtheria.

The blood is thus the great distributor; it distributes the raw materials of life, its waste products, the chemical substances concerned in co-ordination and regulation, and those which help in the protection against disease. It is a middle-man between each living part of the body and every other, and its circulation, begun in the first weeks of life, must continue uninterruptedly if life is to be maintained. The only rest which the heart can have is between each beat and the next.

There is in the frog, as in man, another set of spaces filled with fluid which are circulatory in function. These are the lymphatics (Fig. 25). Into them any surplus fluid which has passed from the blood into the tissues is drained out, and this fluid, for reasons we shall see later, is not red but colourless. In man the lymphatics start as small irregular spaces, which unite and eventually drain into one of the large veins. In the frog, however, the small lymph spaces unite into very large lymph sacs, the biggest of which, filled with clear fluid lymph, lie between the skin and the muscles of the body wall. To pass lymph from these into the veins, special lymph hearts exist —two pairs of small muscular sacs pumping after the fashion of the true heart. The faint pulsation of one pair of these can be seen in life, just anterior to the cloaca, on the dorsal surface between the backbone and the hip bones: the other pair is below the shoulder-blades.

The frog can move from place to place, and special organs are needed for movement as for digestion and circulation. The actual parts of the frog by which movement is effected are the muscles or flesh. Muscle is a form of living substance which has the property of contraction, or altering its shape, when stimulated in certain ways; it shortens its length, while increasing in breadth. There is, for instance, a layer of muscle arranged circularly round the gullet (as also round the rest of the gut). When this contracts in any one place, it narrows the tube of the gullet there; and it is by a wave of such contraction travelling from top to bottom of the gullet muscles that food is automatically passed down into the stomach. Or again, when the muscles of the bladder contract, the cavity of the bladder is made smaller and urine is expelled. For moving the animal from place to place on land, however, some part of the body must be held fixed against the ground, and the rest of the body moved relative to this fixed point. To accomplish this, a jointed framework is necessary; and this is provided

in the frog by the skeleton, composed of substances known as bone and cartilage (Fig. 4).

The skeleton, however, serves other purposes besides enabling the contraction of the muscles to effect movement. For one thing it acts

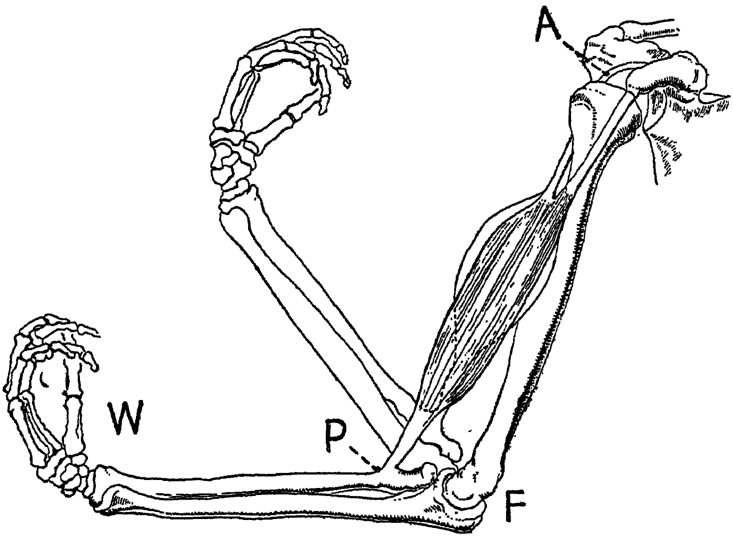


FIG. 4. The biceps and skeleton of the human fore-limb, to illustrate the lever action of muscles. The muscle is attached to the shoulder-blade at *a*, by means of two tendons; and to the radius bone in the fore-arm by one tendon at P. F is the fulcrum of the lever system, represented by the elbow-joint; the power is applied at P; and the hand represents the weight to be raised, W. When the biceps contracts it becomes thicker and shorter, and consequently the hand and the fore-arm are raised. (Huxley, *Lessons in Elementary Physiology*, 1915.)

as a support to the whole body. Living substance itself is soft and semi-fluid, with a specific gravity very slightly greater than that of water. Animals which live in the water, therefore, are almost entirely supported by the water; but a land animal of any size requires a firm skeleton to prevent it collapsing under the force of its own weight. A frog without a skeleton would spread out, if in air, like an egg taken out of its shell; whereas jelly-fish far bigger than frogs can manage to preserve their shape in water with no support except their watery jelly.

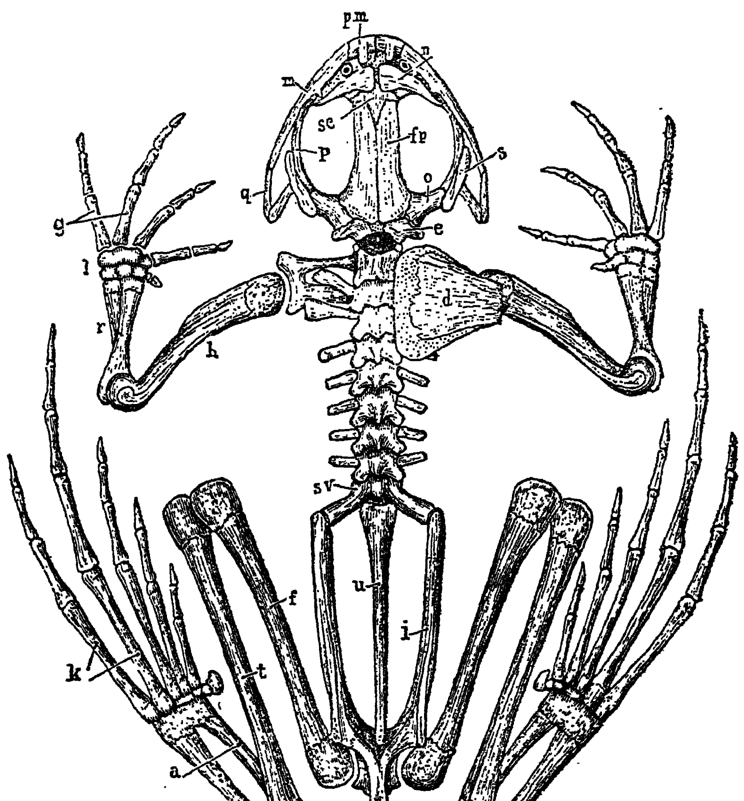


FIG. 5. The skeleton of a frog. Note the skull, with cranium (*fp*), auditory capsules (*o*), nasal capsules (*n*), jaws (*m*, *q*, *p*), orbits (between cranium and jaws); backbone composed of nine separate vertebræ and a rod (*u*) representing several vertebræ fused together; shoulder girdle (the shoulder-blade (*d*) removed on the left side to show the ventral portions of the girdle); fore-limb, with humerus (*h*), fused radius and ulna (*r*), wrist (*l*), and digits (*g*); pelvic girdle, the dorsal part of which (ilium, *i*) articulates with the sacrum (sacral vertebra, *sv*); and hind-limb, with femur (*f*) articulating with the pelvic girdle, fused tibia and fibula (*t*), ankle with elongation of two bones (astragalus, *a*, and heel-bone or calcaneum, *c*), and digits (*k*). (Marshall, *The Frog*, 1923.)

outer world. Through the proprioceptors we are aware of the position of the various parts of the body, which of course depend on the degree of contraction of a number of muscles, the degree of bending of the various joints, and upon our position with regard to the vertical. The receptor organs include the sense organs, but are not the same thing, since many receptors when stimulated do not always give rise to sensations, and some never do.

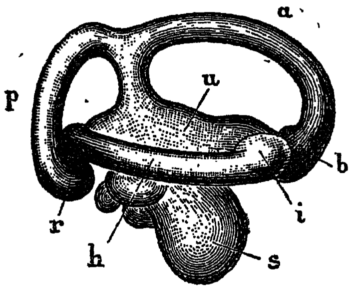


FIG. 6. The right inner ear (membranous labyrinth) of a frog, seen from the outer side. *a*, *p*, and *h* are the three semicircular canals (anterior, posterior and horizontal respectively), in the three planes of space, with swellings (ampullæ) at *b*, *r*, and *i*. *u* is the utricle, *s* the saccule. From the saccule the cochlea of mammals develops (*see* p. 210). (Marshall, *The Frog*, 1923.)

A receptor organ, in fact, is in itself responsive to one particular sort of change, but its stimulation may or may not give rise to a sensation in consciousness. They enable action to take place in response to changes inside or outside the body, and in some cases in addition the animal is through them made aware of these changes by sensations being aroused. Receptor organs may be large and important structures; such, in the frog or man, are the eye, the ear, and the organ of smell. By means of the eye it is possible for the frog to be aware of the form, size, and probably colour of objects at a distance; if it had no ear it would not only be unable to perceive sounds, but also to balance itself. The nose enables it to detect distant objects by reacting chemically with particles which they give off into the air.

Taste, like smell, is a chemical sense, but gives information not about distant objects but about those which find their way into the mouth; a number of very small taste organs are scattered over certain parts of the tongue.

The receptor organs for touch, pain, heat and cold are all microscopic, and are scattered over the surface of the body, more abundantly in some regions than in others.

In all the higher animals, receptor organs are always connected

with the nervous system. This consists of the central nervous system, and the nerves and ganglia (Fig. 7). The central nervous system includes the brain and the spinal cord. The brain of a frog is a soft whitish organ, richly supplied with blood, and of a complicated shape. We can distinguish three main divisions in it, the fore-brain, the mid-brain, and the hind-brain. In the fore-brain, the largest part (and as we shall later see, in some ways the most important) is the cerebrum, consisting of the paired cerebral hemispheres. In front of this are olfactory lobes connected with the nerves of smell; behind it a small part with curious stalked bodies arising from it, the pineal above and the glandular pituitary below. The mid-brain is small; the hind-brain again large, and divided into the cerebellum and the medulla.

The spinal cord is joined to the medulla. It runs the length of the backbone, and has no specially distinguishable parts. From both brain and spinal cord spring a number of white branching structures, the nerves. Those from the brain are called the cranial nerves. When traced out, most of them are found to end in the sense organs and muscles of the head, but one pair in particular, the vagus nerves, run right down into the body and send branches to heart, lungs, stomach, and other organs. On the other hand, none of the spinal nerves, from the spinal cord, run up into the head (except the first, which supplies the throat region); they end in the receptor organs of the body and in the muscles of the limbs and body wall.

Down the back of the body cavity there may also be seen a double chain of nerves which is not directly connected with either brain or spinal cord. On this chain there is typically a swelling or ganglion opposite each spinal nerve, and this ganglion is connected with the corresponding spinal nerve by a thin nerve branch; the chain also continues into the head, where similar connexions are made with some of the cranial nerves. This set of nerves is called the sympathetic system; the branches given off from it run mainly to glands and to muscles not connected with the skeleton, but forming part of internal organs such as those of blood-vessels, of the digestive tube and of the bladder.

What is the function of the nervous system? When we examine a nerve we find that it is composed of a bundle of nerve fibres, in the

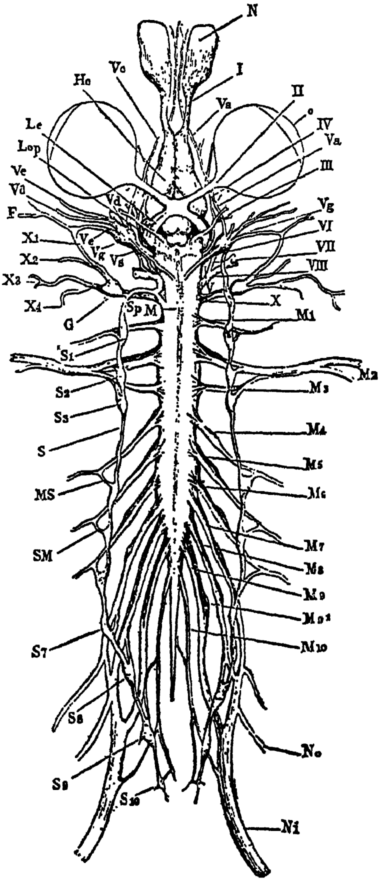


FIG. 7. The nervous system of a frog, in ventral view. The membranous nasal sac (N) enclosing the organ of smell, and the eyeball (*o*), are also shown. I, olfactory nerve from nose; II, optic nerve from eye; III, IV, VI, nerves to eye muscles; VII, facial nerve; VIII, nerve from ear; X, vagus nerve to heart, stomach, lungs and larynx; M1–M10, the ten spinal nerves; S, sympathetic chain, with sympathetic ganglia; S1–S10, each connected with their corresponding spinal nerves. Note the junction of M2 and M3 to form a plexus for the arm, and of M7–M10 to form one for the leg. In the brain the cerebral hemispheres (He) are shown, with the olfactory lobes in front of them. Behind the X-shaped figure made by the junction of the optic nerve lies the pituitary. M marks the junction of the medulla oblongata and spinal cord. (Marshall, *The Frog*, 1923.)

same way as an electric cable is composed of a bundle of wires. Each of these nerve fibres is a microscopic thread of living substance which has the power of conducting impulses or excitations very rapidly along its length, roughly as a wire conducts an electric current.* And the nerves themselves are like cables each containing a number of wires. The nerve-fibres from receptor organs run in nerves until they reach the central nervous system, and there split up into a number of very fine branches.

Other nerve-fibres carry impulses outwards and are connected with what we call effector organs—organs which are capable of active work, the muscles and the glands. The two sorts of nerves are called afferent and efferent, because of their carrying messages to and from the central nervous system respectively; or sometimes sensory and motor, because of their main functions.

The ends of the afferent fibres inside the central nervous system are branched. These branches come into contact with those of other cells, and sooner or later with the similar branches of efferent fibres. Sometimes they connect, after a few intermediate steps, with cells which send out efferent fibres in the same region of the cord. In other cases they connect with the end branches of cells whose fibres run up and down within the central nervous system, often up to the brain; but even so the other ends of these fibres are always connected, directly or indirectly, with efferent fibres.†

All messages from receptor organs, therefore, always pass to the spinal cord or brain; within these organs, they are, either directly or indirectly, passed on to efferent fibres; and so finally to muscles or glands. The result on these effector organs may be either to start or to increase their activity ("excitation"), or else to diminish or stop it ("inhibition"). In any case, by means of the nervous system, a change in the outer world or in the body itself is made to exert an effect on the working of muscles or glands, often in quite other parts of the body (Fig. 30).

When an action is carried out thus by an effector organ as the result of a stimulus transmitted to it along nerve-fibres from a receptor organ, it is called a reflex action (or simply a reflex), because the

* In man, impulses are conducted along nerve-fibres at the rate of about 120 metres a second, n a frog more slowly, at the rate of 28 metres a second.

† The point of contact between the branches of two separate nerve-cells is called a *synapse.*

stimulus travels to the central nervous system and is then, as it were, reflected outwards again along the efferent fibre; and the arrangement of organs concerned in it is called a reflex arc. Good examples of a reflex action are the narrowing of the pupil of the eye when strong light falls upon it, and the watering of the mouth at the sight of appetizing food. In both cases the eye is the receptor organ, but in one case the effector organ is a muscle (the circular muscle of the iris or coloured portion of the eye), in the other a gland (the salivary gland).

The spinal nerves and spinal cord, taken by themselves, represent nothing but a huge system of interrelated reflex arcs; in other words, a wonderful arrangement for translating changes in the outer world, through their effects on receptor organs and nerve-fibres, into action. A particular stimulus will automatically call forth a particular action because there is a path (predetermined through heredity) in the nervous system from the receptor organ affected by the stimulus to the muscle or gland which acts. That this is so can be shown by destroying the whole brain of a frog. The rest of the frog is now quite unconscious, but can continue to live for many hours. The limbs hang limp; but if the toes are pinched, the leg will be drawn up; if a drop of acid be placed on the skin of the back, the leg will be raised to wipe it away. It may be noted that the number of efferent paths is considerably smaller than the number of afferent. The nervous system in this respect is like a funnel, with stimuli poured into its broad top, to issue in a narrower stream of action.

What then does the brain do in the frog's organism? In the first place it receives the messages from the large organs of special sense in the head—sight, hearing, smell, and taste. Secondly, it is the main controlling centre of the animal. Thirdly, it (or rather part of it) is the seat of consciousness.* Owing to the first cause, the constant stimulation through the organs of special sense, the brain is in more intimate relation with the outer world, and with more of the events of the outer world, than is the spinal cord or any other part of the frog.

Then there is the question of control. In the spinal cord not all the branches of afferent fibres connect at once with branches of efferent

* In man the fore-brain is known to be the part of the organism with which consciousness is bound up. We presume that the frog, too, possesses some degree of consciousness, and that this is related to the same part of the brain as in ourselves; although the evidence is of course indirect.

fibres leaving the cord; some enter into relation with special fibres which run up inside the cord to the brain, and there make connexions with fibres of the brain. From other parts of the brain, fibres run down the cord again, and come into contact there with branches of efferent fibres. The efferent nerves of the cord, therefore, can be affected first by the messages of the sense organs brought along the afferent fibres, and secondly by messages from the brain. Now the brain, as we saw, is in better contact with the outer world than is the rest of the frog; further, it is the seat of memory. Thus the messages from the receptor organs of the skin and of the inside of the body are sent up to the brain and there brought into relation with messages from more distant surroundings and with records of the past. In just the same way, in an army in the field, the battalions in the line send up reports to headquarters of what they have discovered about the enemy, and of what they themselves are doing; and at headquarters these reports are considered in the light of the much wider knowledge both of present and past conditions, acquired through the intelligence and operations branches. Finally, just as a battalion commander might think that to attack was the right policy and yet might be ordered to remain inactive owing to some situation far behind the enemy's front, of which he knew nothing, so the reflex action which would inevitably take place if the spinal cord were left to itself may be altered or entirely stopped by messages reaching it from the brain. A sneeze, for example, is a reflex action; but we can usually stop it by an effort of will if we realize, for instance, that to make a noise will put us in danger, or remember that there is an invalid in the room who must not be awakened.

Finally, states of consciousness seem to correspond with special ways of setting the connexions in the brain. When we are angry, the brain connexions are so set that messages may run out to all the effector organs concerned in attack and defence; when we are afraid, the machinery for running away is put in readiness; when we are depressed, it means a damping down of all our general activities, and so forth.

The reflex arcs connected with the spinal cord thus represent the machinery by which an animal's actions are possible. But the particular actions carried out depend upon the way in which the brain influences

this mechanism. The range of actions possible to a frog is much less than that possible to a dog or monkey; and that of a dog or monkey, again, very much less than that possible to a man. The differences between the spinal cord machinery of the three types of animals, however, is comparatively small; it is through differences in the brain that the same general machinery can be adapted to many more situations and made to carry out a far greater number of distinct actions.

By means of the nervous system, then, as well as through the blood system, co-ordination is carried out. But whereas the co-ordination effected by internal secretions in the blood is primarily between one internal organ and another, that effected by nerves is largely between the outer world, as it stimulates the receptor organs, and internal organs. What is more, a much more finely adjusted co-ordination can take place through the nerves than through the blood. Actions like the accurate bringing up of the frog's leg to the particular spot on the back which is stimulated, or my using my pen to write these words, involve just the right degree of contraction of a large number of muscles, and are far more complex and nicely adjusted in detail than the secretion of the pancreas under the influence of the hormone from the intestine, or the darkening of the frog's skin when the pituitary hormone is injected. Furthermore, in the working of the nervous system, we find that one part is in the relation of central headquarters and so dominates or controls the rest, whereas nothing of the sort happens in co-ordination through the blood.

We have not yet mentioned the reproductive system, by means of which new frogs are produced from old; but this will be best treated in another chapter.

So far we have dealt with the working of the frog's organism, and the plan of its structure. It remains to consider the frog in relation to its surroundings. When we do this, we find that there are so many correspondences that they cannot well be due to chance. The common frog spends much of its time in the water; and its hind feet have a web between the toes. It uses its skin for respiration; and lives in damp places. It feeds on small animals; and has a tongue suited for seizing such prey with lightning rapidity. It is preyed upon by various birds; but has a blotched skin to camouflage it, and, furthermore, a skin

which changes colour with its surroundings, becoming darker on a dark background and vice versa. The tree frog, on the other hand, lives among the leaves of trees; and it is coloured green. It must climb tree trunks; and possesses special adhesive pads on its feet. The tongue of a frog would be of no service to a grass-eating cow, nor its webbed feet to a dog or cat, nor its skin to a desert-dwelling animal.

In brief, the structure and habits of the frog, like those of all other organisms, fit its surroundings; and we say that it is *adapted* to its particular environment. *How* it is that animals and plants are adapted to their surroundings is another and far more difficult problem, which we must leave for the present.

Our next immediate concern is to penetrate into greater detail of the frog's anatomy. So far we have only considered structures visible with the naked eye or with the help of a hand lens. But by means of the microscope we can submit the frog's tissues to a magnification of several hundred diameters, and see much that was invisible before. This branch of zoology is called histology, or the microscopic anatomy of tissues.

Perhaps the most important fact revealed by these methods is the fact that all tissues are made up of definite units of living substance, usually called cells. The name cell is not a very good one, as it suggests hollow boxes, and the living cell is not hollow and is in no sense like a box. However, the name was first given to the hollow boxes of which cork and pith are seen to be composed when examined under the microscope; these are the dead cases of once living tissue units. Then the name was transferred to the living tissue units of plants, living contents, box, and all; and finally, when it was clear that the slimy contents were the essential and the box something incidental, found in plants and not in animals, the term became restricted to the contents, and the box of cellulose in plants was called the cell wall.

A cell is the functional unit of living substance or protoplasm. This semi-fluid, almost transparent material, generally containing granules, is a complex mixture of substances, some of which in their turn are also of extreme chemical complexity. Cells, both of animals and plants, normally possess a specialized cell membrane at the surface, which regulates the passage of materials in and out of the cell, and a

central usually rounded body with a definite membrane of its own, the nucleus. The protoplasm apart from the nucleus is called the cytoplasm.

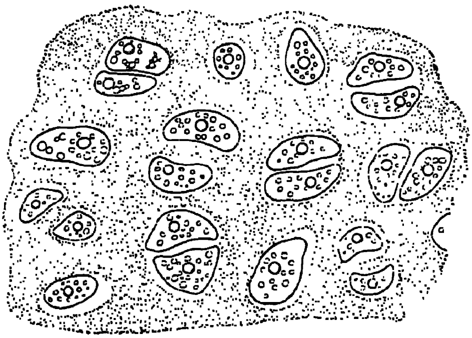
All tissues are made up of living cells, together in some cases with dead substances produced by cells; and each tissue consists of one or a few characteristic kinds of cells, arranged in a characteristic way.

Blood is the tissue (if we may stretch the term "tissue" to cover a mass of cells not joined together, but moving freely in a fluid) which is most easily examined microscopically. If we look at a small drop of frog's blood under the microscope, we shall see that it contains thousands of cells. The commonest type is a flattened oval in shape, with its cytoplasm of a faint straw colour, and containing a central uncoloured nucleus. In bulk these corpuscles give blood its red colour, and are called the red corpuscles. Their colour is due to a pigment called hæmoglobin which they contain, and by means of which they convey oxygen round the blood stream (Fig. 24). Human red corpuscles are smaller, bi-concave, and without a nucleus. Besides these, there will be seen a number of smaller, uncoloured bodies, capable of slow movements and alterations of shape; these are called the white corpuscles. Most white corpuscles have the power of devouring bacteria and other foreign particles (Plate 12). When they collect in large numbers, inflammation is often found. They are the body's microscopic policemen and scavengers.

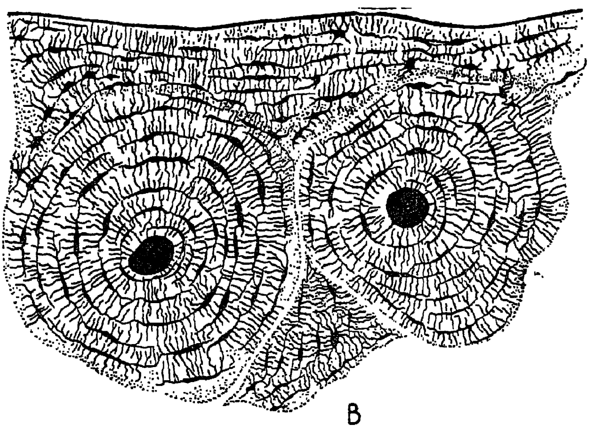
Next we distinguish a whole group of tissues which form linings to surfaces, whether external or internal; such a lining is called an epithelium. The body cavity, for instance, is lined by a single layer of flattened cells fitted together like a simple jig-saw puzzle; the absorptive lining of the gut by narrow cylindrical cells; the lining of the windpipe by cubical cells armed with tiny lashes or cilia which beat uninterruptedly and drive any small foreign particles up and out of the windpipe. The outer skin, or epidermis, on the other hand, is an epithelium of many layers of cells. The lower ones are roughly cubical, and are continually producing new cells which become gradually transformed into horny plates to be rubbed off on the outer surface as scurf; in this tissue, therefore, cells are constantly dying throughout life, being sacrificed for the good of the whole organism. The horny layer is much better developed in land

forms than in water animals or the moist-skinned frog (Fig. 35).

Organs of touch are scattered just below the epidermis, and numerous glands open on it—sweat glands, for instance, in man,



A



B

FIG. 8. (A) Section of cartilage (from frog's breast bone) highly magnified. Cartilage cells, several of them having recently divided into two, are lying in the tough matrix which they have secreted. (B) Section of bone (from pig's thigh bone) highly magnified. In life, blood vessels run in the large circular black spaces and bone cells occupy the smaller branched spaces. The intermediate material is the bone matrix. (From Bourne.)

slime glands in the frog. *Glands* are those parts of the organism whose function it is to extract or manufacture particular substances from the blood, whether they are substances of which the organism will make use, or substances of which it must rid itself. The pancreas secretes pancreatic juice for use in digestion, the kidneys secrete urine for elimination from the system. The simplest kinds of glands are single cells, such as the mucus or slime cells which are scattered among the absorptive cells of the frog's intestine, and secrete a lubricating fluid. Most glands, however, are many-celled tubes or

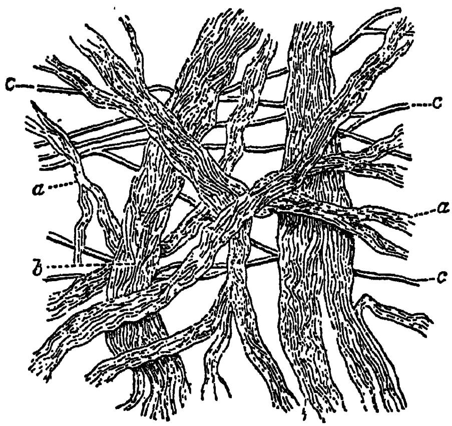


FIG. 9. The fibres of ordinary connective tissue after removal of the cells. *a* and *b*, bundles of white fibres; *c*, single elastic (yellow) fibres. (Huxley, *Elementary Lessons in Physiology*, 1915.)

pockets of epithelium, either unbranched or slightly branched like the glands of the stomach, or much-branched like the liver or salivary gland. Their cells are usually more or less cubical. Generally little spherules of the substance which they secrete are to be seen within their cells; after a gland has been in action, however, these are seen to have disappeared—they have been discharged (Fig. 27).

The cells of muscles are very remarkable structures. The simplest are found in smooth muscle; they are very much elongated, and are

marked with a number of fine fibrils along their length. In voluntary muscles (those attached to the skeleton), each unit is made of a number of cells run together, as is evidenced by the number of nuclei which it contains. Further, in addition to longitudinal fibrils there are a number of transverse bands across the fibres of voluntary muscle. The presence of these bands is somehow associated with greater rapidity in contraction.

Next we have a group of tissues called the supporting tissues. They have the property of secreting dead substances out of their living selves, and by this means building a skeleton or framework. In gristle (cartilage), for example, a number of roundish cells can be seen, embedded in a stiff jelly-like substance which they have produced. The same is true of bone, save that there the cells are usually arranged in definite systems, often concentric, and that fine branches from them penetrate the ground substance in every direction. Connective tissue, on the other hand, which binds up every organ in a fine firm sheath of tissue, has a number of scattered cells which produce bundles of fibres, interlacing in every direction, and giving great tensile strength combined with elasticity. If we could conjure away every other tissue of the body, we should still see the outlines of every organ, including the course of every vein and artery, every nerve, preserved for us in this pervading scaffolding of connective tissue (Figs. 8, 9).

Nerve cells or *neurons*, as befits their remarkable functions, undergo perhaps more change during their development than does any other type of cell. In early stages, they are irregularly rounded, like most other cells at this period. After a time, however, a prolongation grows out at one end, and one or more similar prolongations at the other. These continue to grow, and become the conducting nerve-fibres we have already spoken of; some of them may reach relatively enormous lengths, the muscles of the toes, for instance, being supplied by fibres which run all the way from cell bodies in the spinal cord—a distance of several yards in the largest animals known. A nerve-fibre is thus always attached to a nucleated cell body, and cannot exist without it; if a nerve be cut, all the fibres which are no longer attached to cells die; whereas those parts of them which are still in connexion with the cell bodies will live and regenerate. The nerve-cells in parts

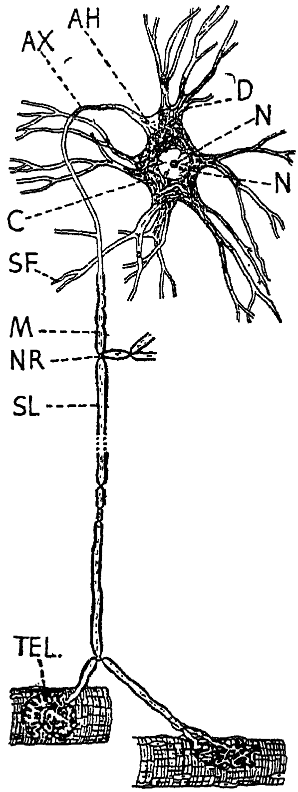


Fig. 10. Diagram to show the main parts of a nerve-cell (a motor neuron from the ventral horn of the grey matter in the spinal cord). *ah*, origin of main outgrowth or axon, *ax*. *c*, cell body. *d*, shorter branched outgrowths (dendrites); their fine terminal branches are not shown. *m*, *sl*, sheath cells round axon, separated by nodes (*nR*); at the one marked, the axon has divided. *sf*, another branch of the axon. *n*, nucleus of the nerve-cell with its nucleolus. *tel*, end plate formed by the tip of the axon, through which impulses are transmitted to the muscle fibre (in reality, the axon will always be much longer relatively to the cell body).

of the cerebral hemispheres are remarkable for the degree of branching shown by their processes; it is probable that these are concerned with memory, and in man with the association of ideas (Plate 3 and Figs. 10, 34).

In the same sort of way in which a substance is chemically composed of molecules, so the higher animals and plants are built of cells. They too, of course, are in their turn composed of molecules, and those of atoms; but the cells are the smallest definable *biological* units.

In a sense, the body is a colony of cells. In a beehive, the lives of the individual bees are subordinated to the good of the colony; so too the individual cells are subordinate to the good of the body, but the subordination is far more thorough, and the "colony" can act as a single whole far more efficiently than the hive.

This it can do in spite of the enormous number of cells which it contains. If human beings were blood corpuscles, the population of London would almost fit into a cubic millimetre of human blood, and the population of the world into a dozen drops.

A frog, then, is a mass of living substance organized on a particular plan, and this plan bears a definite resemblance to that of human beings, although it is altogether different from the plan on which both crayfish and cockroach, for instance, are constructed (Plate 2 and Figs. 73, 75). It is composed of cells; these joined together into tissues; these again into organs and systems of organs. Each organ is constructed so as to work in a particular way, which is normally for the good of the whole organism to which it belongs. Some organs, like the digestive system and the glands, carry on chemical work; the skeleton is a passive support and protection; the blood system is the go-between for all the others; the muscles by changing their shape move the whole organism or alter the state of the organs; the receptors are like windows into the world of events. But through one window one set of events only can be seen, through another window only another set; the nervous system ensures that the reports of different kinds of events shall be co-ordinated, and that on the whole the right response shall be made to the right event. Thus the nervous system, together with the chemical regulation effected by way of the blood stream, makes it possible for the animal to act as a unity, as a single whole, and so to deserve the title of *organism*.

DEVELOPMENT AND HEREDITY

FROGS GROW OLD as well as men, and will die of old age even if they have not previously met death by some accident. If there is to be a race of frogs, there must therefore be a continual production of new frogs to take the place of the old. Our next inquiry must be into the method adopted to ensure this *reproduction*.

If we run an individual frog's history backwards through our minds, as a film can be run backwards through a cinema, we find that the full-sized or adult frog was preceded by a young frog of much smaller size, but of the same general shape and structure. Before this, however, the frog was so different as to merit a different name; it was a tadpole, lived only in the water, fed mainly on vegetable food, had only rudimentary legs, and swam with a tail. It did not breathe by lungs, but by gills; these are branched outgrowths of the body wall with many capillaries just below a very thin skin. They grow on the outer borders of slits which lead from the cavity of the mouth to the side of the neck, and, since water is continually being sucked in at the mouth and then forced out through these gill-slits, they can be always taking up dissolved oxygen from the water and passing carbon dioxide out into it. In large and medium-sized tadpoles, the gills and gill-slits are covered by a flap of skin or gill cover; but in quite small ones the gills stand out free on the side of the neck. As the adult frog grew out of a smaller frog, so the large tadpole has grown from a smaller tadpole of the same general form and containing the same systems of organs, except that it is altogether without limbs. The small tadpole, in its turn, hatched out of a glutinous covering, which with several hundred others formed a mass of frog spawn.

If we had gone farther back and examined the developing frog inside the jelly a few days before hatching, we should have seen that it still had the general form of a tadpole; but its gills were mere knobs, its tail not fully formed. Before that again there was a time when, although the general plan of the internal organs was the same, the organs themselves were not present as working pieces of machinery, but merely blocked out in an undifferentiated state, with their com-

ponent cells not yet specialized as in the adult. The liver at this stage, for instance, was represented merely by an unbranched tube; the heart was an S-shaped blood-vessel, as yet without muscles or valves; the chief parts of brain and spinal cord could have been seen, but in a much more rudimentary shape than in the full-grown frog, and with

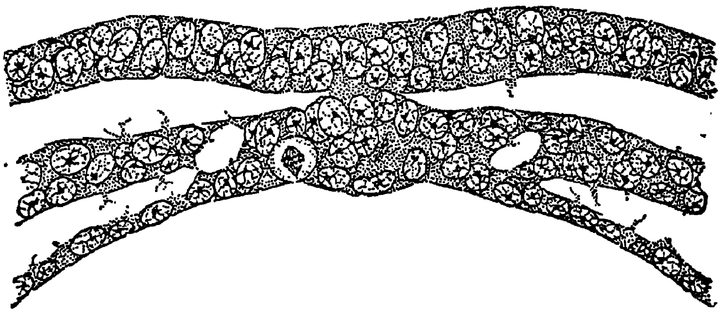


FIG. 11. Transverse microscopical section across very young cat embryo in the germ-layer stage. Above, ectoderm (neural folds not yet developed); below, endoderm; between, mesoderm. In the centre the layers are still united. A mitolic figure is seen just to the left of the centre ($\times 400$). (Dahlgren and Kepner, *Textbook of the Principles of Animal Histology*, 1908.)

no nerve-fibres yet formed by outgrowth from their cells (Plate 4 and Fig. 12).

Still earlier, the developing animal had no particular resemblance to a tadpole, and even the main organ systems were barely recognizable. The future brain and spinal cord, for example, were represented by a groove along the back; the digestive system was an irregular space within a mass of yolk in the interior. Before this, the organism (when passing through what is termed the gastrula stage) was quite spherical, consisting of an outer sheet of several layers of small cells, an inner sheet mainly composed of big yolk-laden cells surrounding the cavity which is the first rudiment of the gut, and a middle sheet between the other two (Plates 4, 5, and Fig. 11).

A day or so earlier, in the *blastula* stage, there was but one sheet of cells, and no digestive rudiment. Earlier still, there were only a few large cells; and at the last, we can trace our frog back to a single very large cell, black above and white below, loaded with reserve food in

the shape of yolk, and containing but a single nucleus. This is the fertilized egg (Plates 4, 5).

"What is the origin of the fertilized egg?" is the next obvious question. But before attempting to answer this, we must go in somewhat more detail into the actual progress of development.

This can be divided into a number of periods. The egg contains plenty of yolk, in order to provide food for the young frog before it can feed for itself. It is consequently a very large cell, and the first step to be taken is to divide it into cells of a more convenient size—the bricks to be used in the future building. The egg divides into two, these into four, and so on, until the blastula stage is reached.

This marks the close of the first period, usually called the period of segmentation. The second period ends in the formation of a rough—a very rough—ground plan of the future organism. A fold of the dark, smaller cells grows over the larger yolky cells, and the crack between the inner layer of the fold and the yolk afterwards swells out to be the first rudiment of the digestive system. If you hold one end of a sheet of paper in place and bring the other end down towards the first, you will produce a similar fold; but the movement of the living fold is caused by rapid growth of cells just about the folded part. Between the inner and outer layers of the fold a third layer or cells is split off. Now the first ground plan is ready—there are three distinct layers of cells in existence. The outer layer will later give rise to the epidermis of the skin, the sense organs, and the nervous system; the inner layer to the gut and all its appendages such as liver, pancreas, thyroid, lungs and gill-slits; and the middle layer to the muscles, the skeleton, the connective tissue, the blood system, the kidneys and the reproductive organs. These three primary layers are called germ layers, so that this is the period of germ-layer formation. Segmentation and germ-layer formation are a good deal simpler in forms with less yolk in their eggs. Plate 5 illustrates the simpler course of development in Amphioxus.

In the third period a great advance is made—the main systems of organs are blocked out. The embryo lengthens: a groove forms on the back, deepens, and its sides arch over and meet to produce a tube; this tube is the rudiment of the whole central nervous system, and of most of the nerves. Tiny pits appear on the side of the head,

representing the future nose and ear; and from near the front of the nerve-tube, two hollow outgrowths arise which will form the main part of the eyes. Below the nerve-tube, a long straight rod is nipped off from the top of the gut. This is the notochord, the early and less complicated precursor of the true backbone. On each side of the notochord, the middle layer of cells grows rapidly, and cuts itself up into a series of blocks of tissue, the muscle segments; from these the voluntary muscles will be formed. Below them, a split appears in the middle layer—the rudiment of the body cavity. From its walls a series of funnel-shaped tubes grow out, and their ends unite and form a duct which grows back to open at the hind end—the rudiments of kidneys and of ureters.

The mouth and anus are pierced; outgrowths of the gut produce the pancreas and liver rudiments; other outgrowths reach the exterior and will form the gill-slits. Scattered cells of the middle layer unite to form tubes, and these tubes join up to give the blood-vessels. The main characteristic of the period has been the formation, in a very short time (not more than forty-eight hours at ordinary temperatures) of a great deal of visible structure where very little was to be seen before. We may call this the period of primary differentiation of organs (*see also* Plate 10 (*a*)).

At the end of this period, the laying out of the detailed ground plan, some little time before hatching, the chief organ-systems and organs are thus all present, but they are not yet in working order—their cells are still all of the same general type, not specialized for their various duties. The next, or fourth period, therefore, is primarily chiefly that of the differentiation of the tissues. The gut rudiment, growing capable of digesting, becomes a gut; the muscle rudiments become muscles; the nerve-tube becomes a brain, spinal cord and nerves; and so on with the rest of the organs of the body. This change is accomplished by the time of hatching for some organs, a little later for others. It takes place through transformation of the shape and structure of cells.

In the next period the animal *works*, and becomes self-supporting; feeding and consequent growth are its chief characteristics; but towards its close, preparation is made for the adult stage by the appearance of limbs and of lungs—again first as mere rudiments,

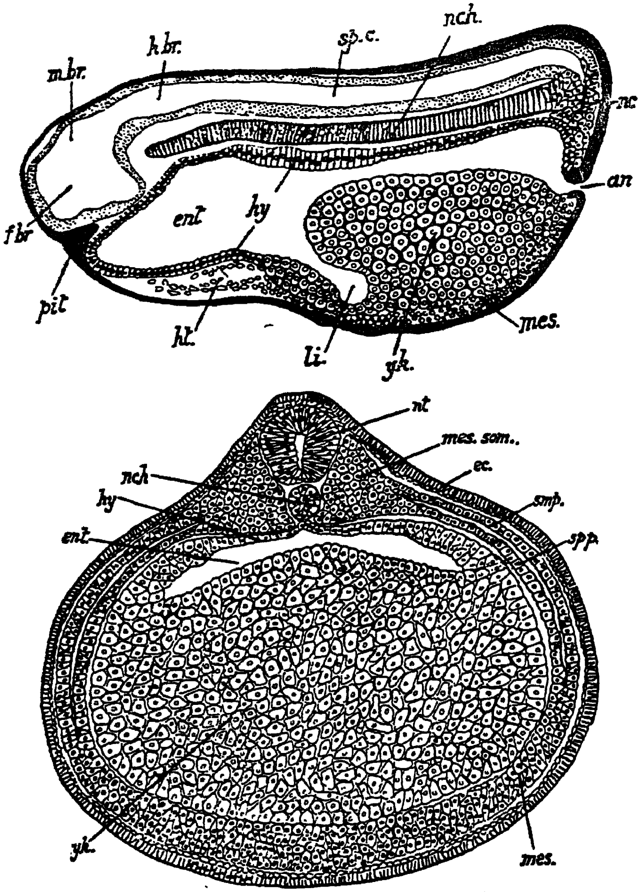


FIG. 12. A longitudinal vertical and a transverse section through a late embryo of a frog. The mouth has not yet perforated; the liver is still a simple tube; the cells from which the heart will be formed are still scattered. Posteriorly the nerve-tube, notochord and hind-gut are still connected. The coelom has appeared as a split in the mesoderm, the upper portions of which are enlarged to form the somites (future muscle segments). The rudiment of the pituitary is being formed from the roof of the future mouth. *an*, anus; *ec*, ectoderm; *ent*, gut; *f.br*, fore-brain; *h.br*, hind-brain; *hy*, endoderm; *li*, liver; *mes*, mesoderm; *mes.som*, somite; *nc*, remains of communication between nerve-tube and gut; *nch*, notochord; *nt*, nerve-tube; *pit*, ingrowth of ectoderm to form pituitary; *smp*, *spp*, outer and inner walls of coelom; *sp.c*, spinal-cord portion of nerve-tube; *yk*, yolk mass.

later as organs capable of working. This is the *larval* period, a larva being a stage in an animal's history when it is self-supporting (and therefore no longer an embryo) but radically different in structure and mode of life from the adult* (*see* Plate 13 (i) and Fig. 79).

The sixth stage, or period of metamorphosis, is a violent transition from larva to adult, from water to land. If we could not actually follow the transformation, it would be impossible to guess that a young frog and a tadpole were stages in one and the same animal's life. The limbs grow rapidly, the shape of head and trunk and the colour of the skin become altered, and there are internal alterations, such as a shortening of the intestine in view of the change from vegetable to animal diet, the remodelling of the skull, and the replacement of much cartilage by bone. But the most remarkable changes are those affecting the tail and gills. These do not drop off, as is still believed by some unobservant people; they are absorbed. They have been built up; now they are unbuilt. Their tissues lose their differentiation, degenerate, and are used as food material. Thus the development of an organ need not always be forwards; it may be reversed.

After the change, another growth stage sets in, which we may call the juvenile period, when the animal is definitely a frog, but not yet grown up. After a time, however, growth slows down, and at about the same time sexual maturity begins. So the eighth of our periods, the adult period, starts. This is the longest of all the periods, and is best developed in the highest forms of life. It is in them a condition in which neither growth nor breakdown has the upper hand, a period of balanced activity, which has been compared to the apparent rest of a "sleeping" top. Frogs, like mammals and birds, have a well-marked adult period in which growth is absent. Many lower animals, however, such as most crabs and shell-fish, go on growing throughout life, and in them sexual maturity, not cessation of growth, is the only criterion of the adult phase.

Finally, however, the ninth period sets in—old age. The metabolism grows feebler, the organs no longer work so well, and even if a violent end does not terminate the animal's existence, as is almost always the case in nature, its life eventually comes to death as an

* When the animal at a corresponding stage is retained within the egg or the mother's body, it is called an embryo or fœtus. (*See* Plates 10 (*b*), 11.)

inevitable close. Such a death is unavoidable and normal; we may call it natural death—a real wearing-out of the tissues and a consequent collapse of the organism like the collapse of the hundred-year-old "one-hoss shay" in the poem.

The development of an animal like the frog, then, consists partly of growth; partly of differentiation or increase of complexity; thirdly, of metamorphosis from one form to another; fourthly, of the attainment of a relatively stable, balanced state, in which growth and differentiation are almost absent; and lastly, of the loss of this stability, the wearing-out of the machine—old age, and death.

Now having traced the development of a grown-up frog from a single fertilized egg, we can return to our question as to the origin of this fertilized egg. If we look at the ovaries or reproductive organs of a female frog in early spring, we shall find in them, and actually produced by them, a great number—one to two thousand—of eggs *apparently* similar to fertilized eggs; a little later in the season, these will be found loose in the swollen lower part of the oviducts, each surrounded with a thin layer of jelly. But if we take these eggs and put them in water, they will not develop. For them to start development, fertilization is normally necessary; and by fertilization we mean union of the egg with a reproductive cell of the male. In all animals, the eggs are cells detached from these special organs of the body, the ovaries (Plate 6 (i)).

The reproductive organs of the male are the testes, small whitish bodies consisting mainly of a number of microscopic tubes. The cells forming the walls of these tubes divide, and some of the fresh cells thus produced change their shape in a remarkable way; the nucleus becomes long and dense, and the rest of the cell becomes transformed into a sharp point at one end and a swimming tail at the other. They are now ripe, and are called spermatozoa or sperms. These are shed into the hollow of the tubes, pass down canals into and through the kidney, and down the ureter, to be stored in a pouch on its side. A drop of the contents of this taken in early April and mixed with water will show thousands of sperms in active movement; a male frog produces billions in a season (Plate 6 (ii) and Fig. 13).

When the female lays her eggs, the male sheds his sperm over them. The sperms are attracted by the eggs, and start burrowing into them.

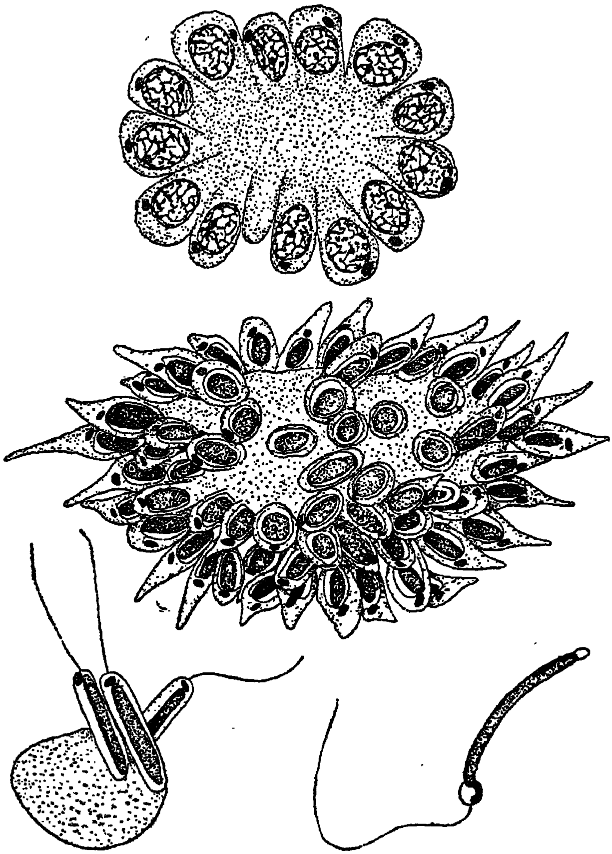


FIG. 13. Four stages in the differentiation of spermatozoa, from the earthworm. Above, a group of spermatids, produced at the close of the maturation divisions. Each has a nucleus and a centrosome. Centre, a similar group showing the first stages in the elongation of the spermatids, their outgrowth, and the elongation and condensation of their nuclei. Below, left, three nearly mature sperms. The outgrowth has become converted into the "tail" (flagellum). There is still a layer of cytoplasm over the nucleus. Below, right, a mature sperm. The tail is further elongated, and takes origin in a "middle piece," containing the centrosome. Then comes the "head," consisting of the much-elongated nucleus, surrounded with a mere film of cytoplasm and tipped with an organ which facilitates the sperm's entry into the egg.

Once one has succeeded in forcing its nucleus inside, a change takes place over the egg's surface which prevents any further spermatozoa from entering. The sperm nucleus then swells up, and becomes very like the nucleus of the egg. The two nuclei meet, and actually unite

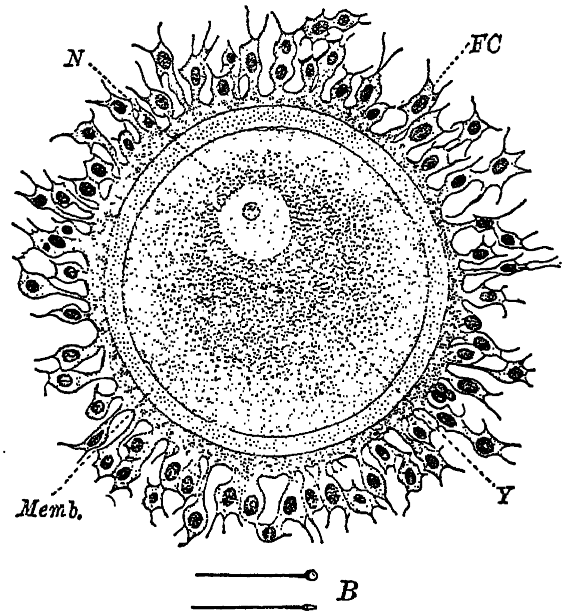


FIG. 14. Human unfertilized egg (oocyte) and sperms, on the same scale. The egg is seen surrounded by its membrane (*Memb.*), and this again by protective and nutritive follicle cells (*FC*). It contains a large nucleus (*N*), which has not yet undergone reduction, and some yolk grains (*Y*). The nucleus contains a nucleolus. Below, at *B*, are two sperms, the lower one in profile. The "head" contains all the nuclear material, condensed. The ovum is about 200μ (0·2 mm.) in diameter.

to form one. This completes the act of fertilization; and only after this does development begin (Figs. 14, 16).

Sexual reproduction in the frog then consists in this: that union of two cells, or at least of the nuclei of two cells, takes place, that the cells at the moment of union are detached and independent, but

previously formed part of the bodies of other individuals of the species; and that the cell formed by their union develops into a new individual.

It has been found possible with the eggs of frogs, worms, sea-urchins, and other animals, to make the egg start its development by artificial means (by chemical treatment in sea-urchins; by heat in starfish; by pricking the egg with a fine needle dipped in blood, in frogs), without any sperm being present, so producing fatherless animals. Some of these have been raised to maturity, and appear normal. Thus fertilization consists of two separate and separable processes—activation, or the starting-off of the egg on development, and the union of the nuclei of male and female reproductive cells.

The two cells which thus unite are called *gametes* or "marrying cells"; and the product of their union is called a *zygote*—something formed by the "yoking together" of two gametes. Usually the gametes are, as in the frog, of two markedly different kinds, the female gamete large and yolk laden, the male gamete tiny and active. This difference between the two gametes, however, is not universal. In many low forms of life, both plant and animal, the two are alike; and in some, as in the single-celled animal Paramecium, only nuclei and not whole cells fuse with each other. Thus the essential fact in sexual fusion is the union of the two nuclei. The difference between the two gametes is only secondary; the size and yolk contents of the egg serve to give the developing embryo a good start in life after fertilization; and the shape and activity of the sperm ensure that the two gametes shall meet.

The race of frogs, then, can be thought of as consisting of a number of continuous streams of living substance. The streams flow for the most part in the form of zygotes, starting as fertilized eggs and developing into mature frogs; but for some of the time they subdivide to flow in the form of gametes, and then such of these streams as do not die out, unite in pairs to become zygotes once more. Or, to put it in another way, the species *Rana temporaria*, or any other kind of higher animal, such as the human species, comprises not *two* but *four* kinds of individuals—male and female zygotes, and male and female gametes. The zygotes are large and long-lived, the gametes small, short-lived, but far more numerous.

To understand fully what this implies, we must again turn back. We have said that cells divide, but have not described the process. As a matter of fact, it is a very remarkable one. When a cell is ready to divide, the wall of the nucleus breaks down, and its contents change from their chiefly fluid state into a number of more solid rod- or strap-shaped bodies, which, because they become coloured by many dyes, are called *chromosomes.* Meanwhile, a star-shaped figure of radiating fibres is seen in the cell. This divides into two, forming a spindle-shaped set of fibres with a radiating "star" at each end, and the chromosomes arrange themselves where the fibres from the two stars meet, in the centre of the spindle. The chromosomes next split right down their length, and the halves travel away from each other, one to one pole, the other to the other. Finally, the body of the cell divides, the set of chromosomes at either pole swells up to form a nucleus again, and there are two cells, each with its nucleus, in place of one (Plates 8, 9, and Fig. 16).

This process of nuclear division (called *mitosis*, on account of the thread-like chromosomes, from the Greek μίτος, thread) ensures that each chromosome is divided exactly along its length. As we shall see, the units which determine the hereditary characters of an animal probably lie along the chromosomes, so that as a result of mitosis a complete set of halved units is distributed to both of the two cells arising at any division; and these halved units, since they are alive, soon all grow up to their original size again.

The number of chromosomes is always the same for a given race of animals or plants; not only this, but often the individual chromosomes can be distinguished from each other by differences of size and shape; and when this is so, they can be arranged in a series of pairs, so that the total number is always even.* In man, for instance, the total is 48; in the fruit-fly, *Drosophila melanogaster*, it is 8; in the Mexican salamander, 28; in Ascaris, 4 (Plates 8, 9), and so on.

At one of the cell divisions just before the formation of gametes, however, the process is quite different. Instead of the chromosomes dividing, the members of a pair come to lie side by side; and at division one whole chromosome of a pair is separated from the other. This process is called the *reduction* of the chromosomes, for owing to it,

* With certain exceptions connected with sex.

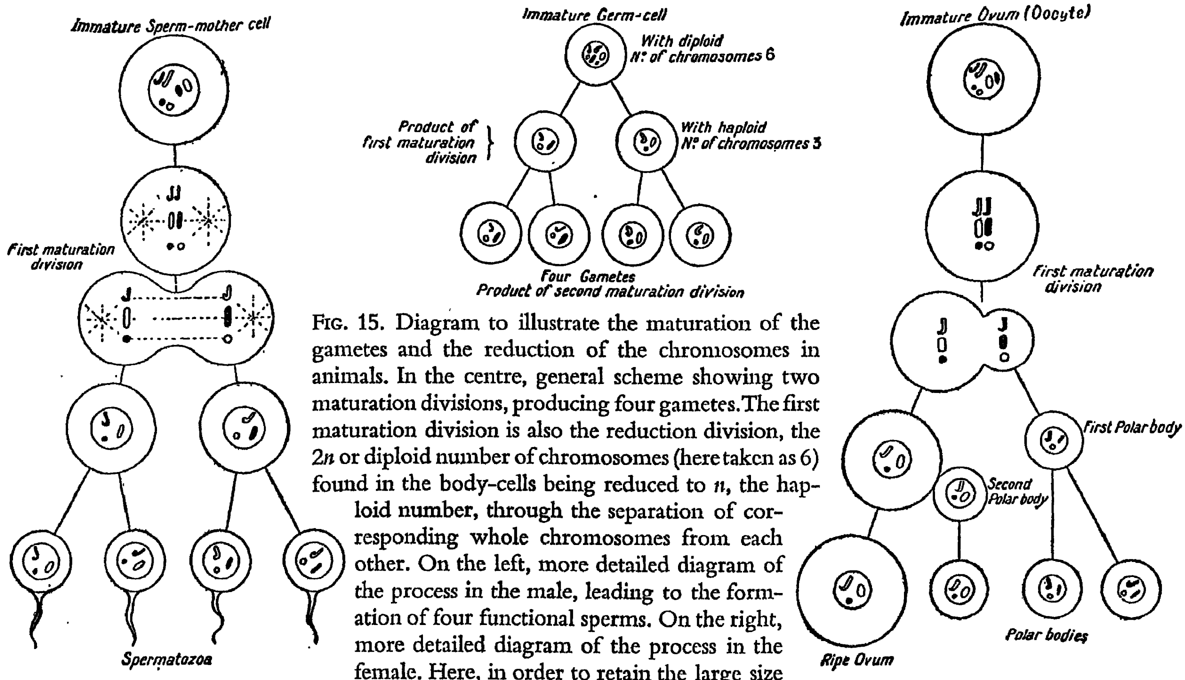


FIG. 15. Diagram to illustrate the maturation of the gametes and the reduction of the chromosomes in animals. In the centre, general scheme showing two maturation divisions, producing four gametes. The first maturation division is also the reduction division, the $2n$ or diploid number of chromosomes (here taken as 6) found in the body-cells being reduced to n, the haploid number, through the separation of corresponding whole chromosomes from each other. On the left, more detailed diagram of the process in the male, leading to the formation of four functional sperms. On the right, more detailed diagram of the process in the female. Here, in order to retain the large size of the egg, three of every four gametes produced are minute and non-functional, and are called polar bodies, while only one becomes a functional ovum. The chromosomes from the father are in black, those from the mother in white.

each of the two cells produced at this division possesses only half the ordinary number of chromosomes for the species (Fig. 15).

Accordingly, gametes have half the number of chromosomes found in zygotes; and the reason the chromosomes of the zygotes exist in pairs is that one member of the pair has come from the father and one from the mother. Thus, the ordinary higher animal or plant has two complete sets of chromosomes, like two packs of cards. This is of great importance in the study of heredity, or, in other words, of the way in which characteristics are handed on from one generation to the next.

A frog gives rise to new frogs, not to toads or lizards; within a single species, such as man, many characters "run in families"—physical characters like black hair, or mental characters like musical talent; and it is a common observation that children inherit traits from their parents and from remoter ancestors. The facts of heredity are often obvious enough. But what is the machinery by which they are brought about? How is it that the tiny, simple-looking egg has the power of developing into the complicated adult, and an adult just of one particular kind? How is it possible that of two eggs, which would be practically indistinguishable under the microscope, one is predestined to produce a red-haired tall boy, the other a dark-haired medium-sized girl?

There is a great deal of evidence to support the idea that inheritance—the transmission of qualities or characters from one generation to the next—depends upon the actual transmission of small units of living substance in the gametes. These units are called the *factors of heredity*, or sometimes still more shortly the *genes*; and there is further evidence that these factors are contained in the chromosomes.

Certain results flow from this—results, for instance, concerning the numerical proportions of different types to be expected on crossing different strains; and, indeed, all the subject matter of the comparatively new science called Mendelism, after the Austrian Abbot Mendel, who first discovered and interpreted the essential facts. Here we are concerned only with some of the more general aspects of the question.

A sexually reproducing animal or plant grows up from a fertilized egg into its adult condition. The fact that it grows up in its own

particular way, that a newt's egg will produce a newt and a frog's egg a frog, although they are scarcely distinguishable and although they grow up in the same pond, must depend on the eggs containing something—let us call it the hereditary constitution—which determines the way each shall grow up.

'Mendel discovered two important laws concerning the way in which the hereditary constitution of an animal (or plant) is related

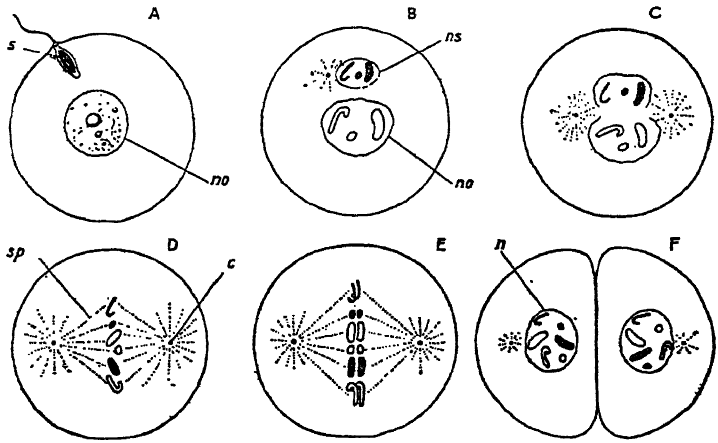


FIG. 16. Diagram of fertilization, continuing Fig. 15. A, the sperm has penetrated the ovum. B, the sperm nucleus is swelling up, the chromosomes are appearing in both nuclei (purely diagrammatic) of the haploid number ($n=3$) in either. The beginning of the spindle is being produced by the sperm. C, fusion of nuclei of sperm and ovum. D, the spindle is fully formed, and all six ($2n$) chromosomes are arranged on its equator. E, all the chromosomes have split longitudinally. F, the fertilized egg (zygote) has divided into two cells, each with the diploid ($2n$) number of chromosomes, one set of three (n) derived from the father in the sperm, the other three from the mother in the egg.

to that of its parents. The first is usually called the *law of segregation*. This implies that the hereditary constitution is composed of a number of self-reproducing units, presumably of a chemical nature, the *factors* or *genes* mentioned above. Normally, there are two of each kind of unit in the body; but before gamete formation, the two members of such a pair segregate, or separate from each other, so that each gamete has one member only of each kind of unit. The second law is that of

independent recombination of units. It sums up the fact, elicited by breeding tests, that the segregation of members of different kinds of units is usually quite independent.

It is easy to see that this is exactly what would be expected if the units were contained within the chromosomes; and, as a matter of fact, this has now been proved to be the case. The adult organism, whether human being, fly, rabbit or pea plant, has two complete sets of chromosomes. The two members of a pair separate from each other at reduction, so that each gamete receives one complete set; recent observations have further shown that the way in which one chromosome pair separates at reduction is quite independent of other pairs. Thus, the single set of chromosomes in one gamete need not all have come in from the father, or all from the mother; there must merely be one of each kind of chromosome present. If we compare the chromosomes to cards, fertilization is like the mixing-up of two packs of cards with different coloured backs. Reduction ensures that this double pack shall be sorted out into two single packs again, but pays no attention to the colours of the cards' backs. Each sorted-out pack will be complete in having one card of each kind, but any of the cards may have either a red or a blue back. Thus it will be most unlikely that, as regards the precise combination of red and blue backs, any of the sorted-out packs will be identical with any other, since the number of possible combinations is so enormous.

Each chromosome appears to contain a large number of units, and the segregation of two units will only be quite independent when they lie in different chromosomes. When they are both in the same chromosome they tend to stick together more often than they separate.*

The units are the really important things in the hereditary constitution, and the chromosomes appear to be merely convenient lengths, so to speak, into which the hereditary constitution is cut up. Accordingly, the cards in our simile should really be taken to represent the separate units, and not the compound units we call chromosomes, which would really be more like suits. If we do this, however, we

* This tendency to remain together is called *linkage* of factors. It is usually not complete—i.e., two factors in the same chromosome can be separated from each other (by a mechanism into which we need not enter here), although they are not so independent as two factors in separate kinds of chromosomes.

must add one more point to make our analogy complete. We must suppose that any particular card need not always have precisely the same value, but that you could have one ten of hearts, say, that was a little above par, and another a little below par. In terms of factors, this would mean that although a given kind of factor always exerted the same general kind of effect in development, yet it might exist under different forms, with slight differences in effect. For instance, we know that one factor concerned with colour production in rabbits may exist in at least four forms, one producing no pigment at all, as in albinos; the next allowing colour to appear in the ears and muzzle and other extremities, as in the Himalayan breed; the next giving the chinchilla coat; and the last allowing full development of pigment. The different forms of one factor are called *allelomorphs*.

So far we have dealt with the generalities of Mendelian theory. They will become much clearer if we look at a couple of examples. If a certain breed of black fowl is crossed with another strain which is white with a few black markings, the offspring will all be unlike either parent, of a type known as the Blue Andalusian, which is a bluish or diluted black colour, with white "lacing" on the feathers.* Poultry fanciers have long tried to get a pure breed of these Andalusians by mating them with each other, but always without success —the birds "threw" blacks and whites as well as producing more blues.

When the subject came to be accurately worked out it was found that when Andalusians are mated with each other, on an average 25 per cent of their offspring are blacks, 25 per cent whites, and 50 per cent Andalusian again. Not only this, but the blacks bred true when crossed with each other, and so did the whites, but the Andalusians always gave the same proportions of blacks, whites, and Andalusians once more (Plate 7 (i)).

These results are at once cleared up if we suppose that the black fowls carry factors which make their chickens grow up black, the white fowls factors which make theirs grow up white.

When a black cock is crossed with a white hen, all his gametes (the sperms) contain one factor for black, all hers (the unfertilized eggs)

* Only certain definite breeds of blacks and whites give this result, not any black crossed with any white.

one factor for white. The offspring will have one of either factor; and their interaction will bring about the so-called blue colour. Exactly the same result will happen if a white cock is crossed with a black hen.

When a blue cock and hen are bred together, the gametes, whether

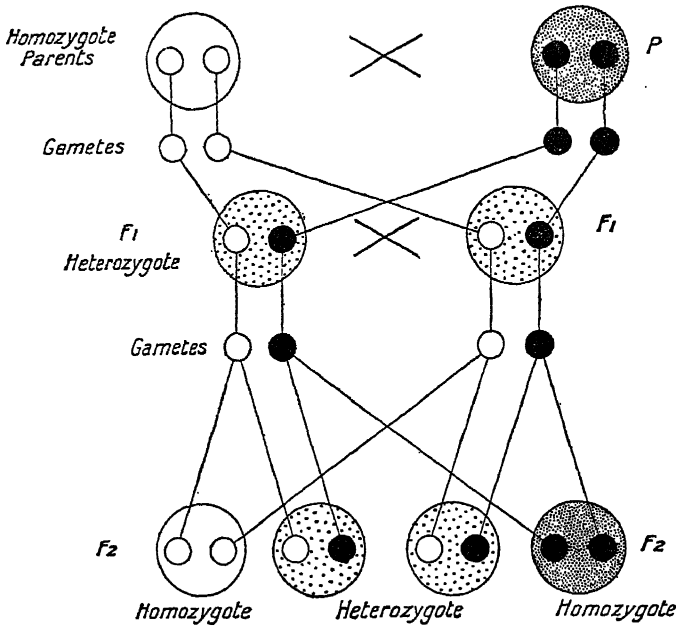


FIG. 17. Diagram to show how the Mendelian conception of hereditary units (factors, genes) explains the foregoing results. The organisms are represented as large circles, the genes as small circles within them. In the gametes, only the genes are represented. Unshaded represents splashed-white; black represents the gene for black, and close dotting visible black; sparse dotting represents visible blue.

male or female, will contain *either* a factor for black, *or* a factor for white, but not both. Let us call the factor for black *B*, and that for white *b*. A *B*-bearing female gamete may be fertilized equally well by a *B*-bearing or a *b*-bearing gamete; and similarly for a *b*-bearing female gamete. Thus, four possible combinations of gametes (as

regards *B* and *b*) may occur at fertilization, and, on the theory of chances, will occur on the average equally often:

(1) *B*-bearing by *B*-bearing. (3) *b*-bearing by *B*-bearing.
(2) *B*-bearing by *b*-bearing. (4) *b*-bearing by *b*-bearing.

(1) will give a chick with two black factors, therefore black; (2) and (3) will give Andalusian chicks once more; (4) will give white chicks. Not only this, but out of every hundred chicks on the average one-quarter will be black, one-half Andalusian, and the last quarter white. This is made clearer by the diagram (Fig. 17).

According to Mendel's second law, factors for different characters are inherited independently of each other. For instance, to take fowls once more, the ordinary type of comb, called single, depends on one form of a particular factor; that called rose, which is low and long, upon another. When a cross is made between birds with these two sorts of comb, the hybrid is indistinguishable in appearance from the pure "rose" stock. This introduces us to the fact that one form of a factor may mask another, and be what is called *dominant* to it. But the factor for single-comb is still present in the hybrids, as is shown by breeding tests. For whereas the original pure-bred rose-comb stock gives nothing but rose-combs, the hybrids crossed with each other give 25 per cent pure-breeding singles, 25 per cent pure-breeding rose-combs, and 50 per cent hybrid rose-comb birds that again do not breed true. That is to say, the difference between single- and rose-comb depends upon a difference between two forms of the same hereditary factor.

Now, if we cross a black bird with a single-comb and a white bird with a rose-comb, all the offspring will clearly be Blue Andalusian in colour, with rose-combs. But we might expect either of two things to happen in the second generation. Either the factors for black and single will stick together when the first generation forms its gametes; and then the only pure-breeding types we shall get will be black single-combs and white rose-combs again, like the grandparents. Or else the factors can separate; if so, then we shall get gametes containing the factor for white with that for single-comb, and those containing factors for black and for rose-comb, as well as the other two types. In this case, in addition to types which will not breed true, we should get four pure-breeding types in the second generation—not only

blacks with single-combs and whites with rose-combs like the grand-parents, but also two new types, blacks with rose-combs and whites with single-combs. And this is what actually happens. This again is most simply shown in a diagram. Let us call *s* the factor for single-comb, *S* the other form of the factor, responsible for rose-comb. Then the results are as follows:—

parents	*BB.ss* (black, single)	×	*bb.SS* (white, rose)
parents' gametes	*B.s*	×	*b.S*
1st generation		*Bb.Ss* (Andalusian rose, but not breeding true),	
1st generations' gametes	♂ *B.S*, *B.s*, *b.S*, *b.s*		♂ *B.S*, *B.s*, *b.S*, *b.s* in equal proportions.

Each type of gamete has an equal chance of fertilizing any other type of gamete, so that we shall get in the second generation the following pure-breeding types:—

BB.SS (black, rose-comb);
BB.ss (black, single-comb);
bb.SS (white, rose-comb);
bb.ss (white, single-comb);

as well as many other types such as *Bb.Ss*, *Bb.SS*, or *BB.Ss*, which will not breed true.

The fact of the independent segregation of different pairs of factors is of the greatest practical as well as theoretical importance, for it enables us to take to pieces the hereditary constitution, so to speak, and put it together again in new ways. More definitely, it enables us to take one particular Mendelian character which happens to be desirable in an otherwise undesirable strain or breed, and to combine it with other desirable characters in another breed. This has already been done with great success in wheat in the experimental plant-breeding station at Cambridge.

A great deal of Mendelian work has been done with the tiny fruit-fly Drosophila, of which over ten million have been bred by

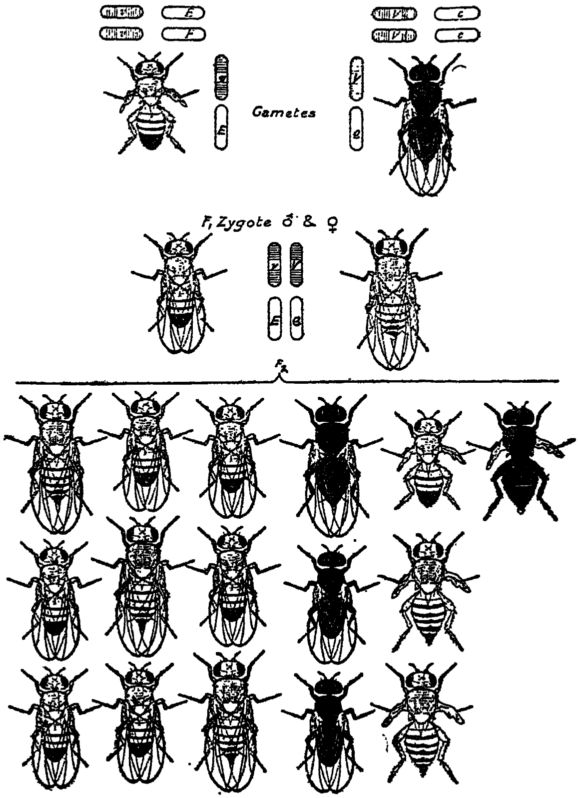


FIG. 18. To illustrate Mendel's second law, by means of a cross between two strains of the fruit-fly *Drosophila melanogaster*, one pure for the recessive gene v, determining vestigial wings, the other pure for another recessive gene, e, determining ebony body colour. The corresponding genes for the dominant wild-type characters are styled V and E respectively. The two genes are lodged in different chromosomes. The chromosomes, together with their contained genes, are represented diagrammatically. The F_1 contain both V and E, and therefore show a reversion to wild-type. In the formation of the gametes of F_1, segregation of V–v and E–e takes place independently. Thus four kinds of gametes are produced, VE, Ve, vE and ve. These, uniting at random, give, out of every sixteen individuals in F_2, 9 wild-type, three long-winged ebony, three vestigial grey, and one vestigial ebony: one of each type will breed true. The vestigial ebony is a new combination. Either character taken separately shows a 3 : 1 ratio.

duck's egg a duck, even though they are hatched in the same incubator. They, reacting with the environment, determine what the adult organism shall be.

Apparently, however, slight changes sometimes occur in the factors, usually in a single one at one time: these changes are called *mutations*. Whereas an animal may normally have red eyes or a grey body-colour, mutations may arise which cause it, even though brought up in the same conditions, to have pink eyes or a black body-colour. (These particular mutations have actually been found in the little fly Drosophila.) When mutations occur, they are inherited in Mendelian fashion; the separation of pairs of chromosomes at reduction, and the subsequent meeting of various sets at random in fertilization, shuffles and recombines in every possible way any mutations that do occur.

Thus, while the chromosomes in general act as a regulator of the constancy of the race, the occurrence of mutations and their subsequent combination in new ways by sexual reproduction provide the possibility of change. The idea of separate factors is important, for it means that when we are dealing with an animal's hereditary constitution we have not got to take it as an undivided whole, but as something which can be analysed into separate units, just as a chemical substance can be analysed into different elements in definite proportions and arrangement.

With this in mind we can turn to another question. We have discovered in outline how individuals are connected with and related to other individuals of the same species; now we must ask whether whole species are not perhaps connected with or related to other whole species.

There is always a struggle for existence going on in nature. From each pair of frogs that breeds, over a thousand fertilized eggs are produced every season; and yet the number of frogs does not increase from year to year. There is, in fact, in every organism an over-production of young, and consequently competition. Since this takes place in all species, there is what we may metaphorically call a pressure of life; the demands upon space and subsistence are greater than the supply, and in every generation only a few of the young produced can reach maturity.

There is further the fact of the hereditary transmission of characters, and the origin of new characters by mutation and recombination. In other words, organisms are continually varying, and some at least of the new variations can be inherited.

As an inevitable consequence, if a new inheritable variation appears which is of any advantage whatever in the struggle, it will help its possessor to survive, and so will on the average be transmitted to later generations more often than other variations which are useless or in any way harmful. The new variation may be directly useful in competition with the other members of the species, as for instance if it made its possessor more easily able to secure its prey; or it may remove its possessor from competition with the others of the same species by fitting it to another set of conditions. In any case, the struggle or pressure of life on the one hand, and on the other the fact that variation does occur and can be transmitted, will lead to what Darwin called *Natural Selection*—the survival of types possessing useful variations, in preference to any other types.

This will explain the fact that animals are adapted to their surroundings, since the unadapted or less well adapted could not survive; it will also explain the fact that when we find a number of species of animals all possessing the same general plan of structure, the different species are generally adapted to live in different conditions, since any variation enabling its possessor to live in new conditions will remove it from competition with the other members of the species. For instance, the general plan of all frogs and toads is very similar; but some live near water, others in drier places, some altogether in water, others on trees, and so on.

The only explanation, in fact, of the resemblance in structure between different frogs and toads is that they are all in very truth related, descended through millions of generations from a common original ancestor; and the explanation of their differences is that they are due to variation and natural selection, the random raw material of the former being sifted by the latter.

The backbone of the evolution theory is that all species have descended from other pre-existing species, and the backbone of the generally current explanation of evolution is that adaptation is due to variation (mutation) acted upon by natural selection.

Now frogs and toads resemble newts and salamanders in many points of their organization; for instance, in their moist, scaleless skin, in the structure of their heart, and in their development through a tadpole stage; and accordingly, they are all classed together as amphibians. Snakes, lizards, tortoises, and crocodiles, on the other hand, have scales, their heart is a trifle more complicated, and they all develop inside a large-yolked egg with special protecting membranes round them; and they are accordingly all classed as reptiles.

When we classify a number of animals together in this way, we are not merely pigeon-holing them for convenience; we pigeon-hole them in this one particular fashion because we believe them all to be descended from a common original ancestor. The classification aimed at by zoology is a natural classification, aiming at a grouping of animals according to their blood relationships. Thus, we believe that all frogs, toads, newts and salamanders are descended from a common ancestral form with an amphibian organization; and all snakes, lizards and other reptiles from a common ancestor with a reptilian organization.

But the organization of amphibia has many points in common with reptiles, as also with fish, and with birds and with mammals, including, as we previously pointed out, man himself. All of these animals possess gill-slits and a notochord at some stage of their development, a backbone, red blood, a nervous-system lying along the back, and so forth; they are therefore all classed as vertebrates (or chordates, with reference to the notochord), and there is no escape from the conclusion that, in the course of an exceedingly long space of time, to be reckoned in tens or perhaps hundreds of millions of years, they have all descended from an original common ancestor.

Belief in the occurrence of evolution, quite apart from any theory of how it has happened, is forced upon us by numerous sets of facts, which remain quite unexplained on any other supposition. In the first place, as already mentioned, there is the fact that animals can be arranged in groups (such as the vertebrate group), each group with a single general plan of organization; and that within each group there are sub-groups with their own special modification of the general plan (e.g., birds or the amphibians within the vertebrates).

Secondly, we have the fact that animals during development often

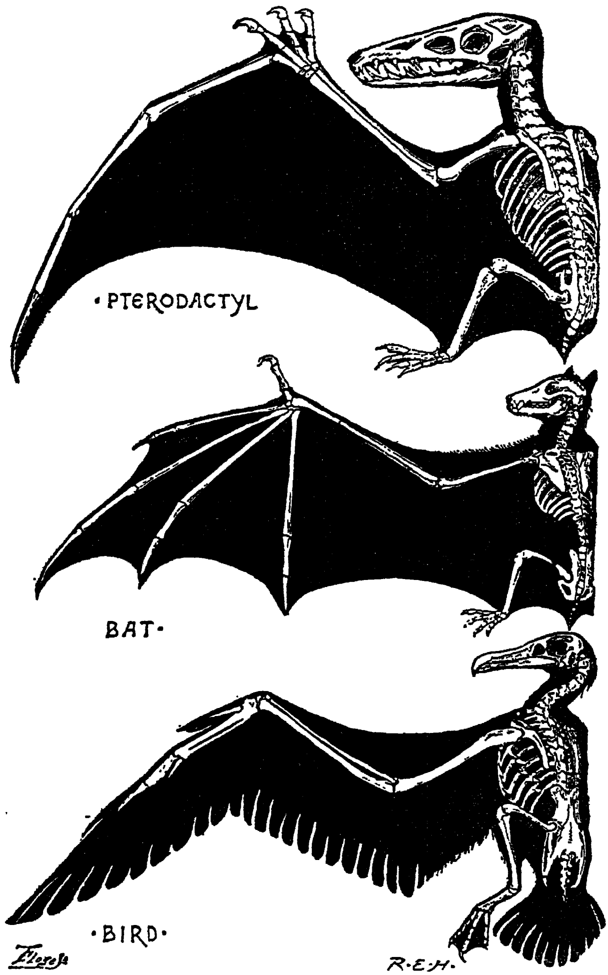


FIG. 19. Homology and convergence. In members of the three classes reptiles, mammals and birds, efficient flying organs have independently evolved (convergence). The fore-limb is always utilized as the main part of the wing, and its general plan is retained throughout (homology). But the details are different in each case. The main support (apart from the upper and lower arm bones) is, in the pterodactyl, the fifth or "little" finger; in the bat, the second to fifth fingers; in the bird, the quills of the feathers. Accordingly, only in the bird is the hind-limb not required as part of the support of the wing, and is left free for other functions.

pass through stages in which they resemble other and usually simpler animals of the same group.* The frog in the tadpole stage has gills, and even the embryos of fowls and men possess gill-slits. Both frog and man, although tailless when adult, possess tails when young (Plate 11). All this is very difficult, if not impossible, to explain unless we suppose that our remote ancestors, and those of birds and frogs as well, lived in water and possessed gill-slits and gills (Fig. 12 and Plate 10).

Thirdly, we have the existence of vestiges. Vestigial, or as they are often incorrectly called, rudimentary organs, are organs which are of little or no use to their possessor, although in related forms they are larger and obviously have a function. In man, for example, the appendix, the hairs on the body, the fold of skin at the inner corner of the eye, and the skeleton of the tail are wholly or partly vestigial. They exist today chiefly because our ancestors possessed them in more developed form. The fold of skin in the inner corner of our eyes, for instance, is the remains of the large movable third eyelid of many lower animals. In whales the whole hind-limb has become vestigial (Fig. 91). If you look at the hairs on the outer side of your arms, you will find that on the upper arm they point obliquely downwards, on the fore-arm obliquely upwards—all of them, in fact, towards the elbow. That is no good to you. But it appears that some of the apes have the habit of keeping their bodies dry in the rain by clasping their hands in front of their neck. The rain runs down the hairs towards the elbows; these are a little out from the sides, and the long hairs stick out from them to form a kind of spout, from whose end the rain pours off right away from the body.

Fourthly, we have the fact that in species of the same group which are adapted to different methods of life, the same plan recurs in organs

* This is called the Law of Recapitulation. It is often stated in the form given to it by Haeckel, that every animal in the course of its individual development tends to recapitulate the history of the race. But the discoverer of the law—von Baer—only stated that the early stages of related animals resemble each other more than the adults. And careful analysis shows that the ancestral stages do not represent the *adult* stages of bygone ancestors, but stages in their development. A man passes through a stage with gill-slits because the embryo of some remote ancestor of man had gill-slits, not directly because the adult ancestor had them. In some cases the characters recapitulated are obviously those of a larva and could not have been those of an adult—those, for instance, of the three-segmented nauplius of Crustacea (Fig. 1). Usually, however, the embryonic ancestral characters are *similar* to the adult ancestral characters, as with the recapitulation of gill-slits or notochord, because the ancestral form possessed the character in question from the earliest stages of its development onwards, as in a fish today gill-slits appear in the stage of primary differentiation and persist throughout life.

adapted to the most different uses. For instance, in the skeleton of the fore-limb in all land animals, although bones may fuse together in some, or altogether disappear in others, the same general plan recurs throughout. This one plan can be seen in the supporting limb of a frog, the paddle-like fore-limb of a whale, the running limb of a horse, the flying limbs of birds and bats, the arm of man. Great difference in detail of adaptation, together with great similarity in general plan—it is difficult to account for this except by common ancestry and a common plan gradually modified in the course of evolution (Fig. 19 and Plate 1 (i)).

Finally, and most conclusively, the fossil remains of animals from earlier periods of the earth's history often show us actual intermediate stages in evolution. For example, the horse has in its fore foot but one finger which it uses, together with two tiny vestigial fingers, the splint bones. If we accept the idea of evolution, we must suppose that these vestigial fingers were once used; and as a matter of fact, if we look at fossils from a certain period (the Miocene period of the Tertiary epoch), we find no true horses, but animals which, though very like horses in most ways, possess three well-formed toes on the foot (Fig. 57 and Plate 1 (ii)).

Again, to take an illustration on a large scale as well as one on a small, if we go back steadily in the history of the earth, we come to a time when man did not exist, or at least no traces whatever of his existence are to be found preserved in the earth's crust. Then, long previously, to one when all the mammals were small and primitive, and all the birds toothed; then, to a time when there were no mammals or birds at all, but great reptiles, many of types now unknown, were the dominant living things; before that, to a time without reptiles, when amphibia were the only land vertebrates; and before that again, to a world without land vertebrates at all, but still with fish in the sea; and finally, a stage is found in which there are no fish, but only marine invertebrates (Figs. 55, 82).

The study of heredity showed us that each individual arose from actual portions of living substance which had once formed part of other individuals. The study of evolution shows that species arise from other species. Within a single species there are a number of parallel streams of living substance flowing through the generations;

but these parallel streams may diverge, and the original species branch into two. Since each species has evolved out of another species, and each individual grows from a detached part of another individual, the whole of life must be looked on as a single mass of living substance, flowing on in time, and divided in the course of its history into a number of separate courses of different size, the main groups, the smaller groups, and the species. The alterations in the branches of this mass of living substance we call evolution.

CHAPTER THREE

EXCHANGES OF MATTER AND ENERGY

ALTHOUGH THERE ARE many features of animal and human life which have not yet been, and perhaps never will be, explained in terms of physics and chemistry, still we can apply to animals, including man, certain great principles, such as the laws of the conservation of mass and energy, without restriction. It will be necessary to give a brief proof of this statement, for if it were not true we could, for example, never be certain that a man was not obtaining energy from unknown sources, in which case physics would be of very little use to the biologist.

If we put a man on a very sensitive balance it is impossible to obtain his weight quite accurately, because at every swing the scale containing the man rises slightly higher. He is losing weight, that is to say losing matter, at every moment of his life. Obviously, some of this matter is water vapour. At the body temperature the breath is saturated with water vapour which condenses into drops on a cold surface or in cold air. Besides this there is a constant slight loss of water vapour from the skin even in the coldest weather, and in very hot weather a man may lose over a kilogram of sweat an hour. Besides water vapour we are always losing carbon dioxide in our breath, and a very little from our skin. This may be easily shown by breathing out through a tube dipped into lime water (CaO_2H_2). The carbon dioxide of the breath combines with this to form a white precipitate of chalk ($CaCO_3$). We can measure the production of CO_2 and H_2O very accurately by putting a man, or better, an animal such as a dog or mouse, into an airtight box. Air is passed into this box through bottles containing strong sulphuric acid (to absorb water vapour) and caustic soda (to absorb carbon dioxide). On leaving the box, it passes through similar bottles, and by weighing them we can determine the animal's output of carbon dioxide and of water (Fig. 20). Nothing else in weighable quantity has been added to the expired air, but it has lost oxygen, as may be proved by taking a sample and making the oxygen in it combine with hydrogen or some other easily oxidizable body.

The man or animal has therefore gained some oxygen from the air and given up carbon dioxide and water to it. Besides these, in the course of a day he will eat, drink and excrete, and we can weigh his food, drink and excretions, and thus construct a balance sheet. The following represents a typical day's balance sheet for a resting man weighing about ten stone.

Gain.	*Loss.*
Food, 1·1 kilograms (of which 0·60 kilogram is water).	Solids (mostly dissolved in urine), 70 grams.
Drink, 1·5 kilograms of water.	Water excreted, 1·3 kilograms.
Oxygen, 0·7 kilogram, or 500 litres.	Water evaporated, 1·1 kilograms.
	Carbon dioxide, 0·82 kilogram, or 425 litres.

This leaves him with a gain of 10 grams for growth, and if he is weighed before and after the experiment he will be found to have gained 10 grams. It is clear from the above balance sheet that much the most important chemical change taking place in the man is the combination of the carbon and hydrogen of his food with the 0·7 kilogram of oxygen to form 0·3 kilogram of water and 0·82 kilogram of carbon dioxide. Now this is exactly the same change which occurs if we burn the food, a fact discovered by Lavoisier in the eighteenth century. Hence, if we put our man or animal into a calorimeter for a day and measure his heat production, and then burn in another calorimeter a quantity of food exactly equal to the amount which he has eaten, we can make an energy balance sheet like the mass balance sheet produced above. Various allowances must be made, of which the most important are the following: Some of the solids excreted are not entirely oxidized, so we must burn them in a calorimeter and subtract the energy thus obtained from that of the food. Again, some energy has been wasted in evaporating water (1·1 kilograms of water require 630 kilocalories* for their evaporation). We must also allow for the energy of any food which is stored up but not oxidized. If the man is in a calorimeter all his external work will be converted into heat by friction; for example, he may be made to ride a fixed

* The kilocalorie of 1,000 calories is the unit of energy which is most useful in human physiology. It is sometimes called the "large calorie."

bicycle with a brake. We can now construct an energy balance sheet as follows for the resting man considered above:—

Gain.	*Loss.*
From food, 2,400 kilocalories. Less waste from unoxidized excreta, 150 kilocalories. Net total gain, 2,250 kilocalories.	Heat lost by conduction and convection, 1,500 kilocalories. Latent heat of water evaporated, 630 kilocalories. Heat used in warming food and drink to body temperature, 60 kilocalories. Total loss, 2,190 kilocalories.

This leaves him with 60 kilocalories stored up (probably mostly as fat) for future use. It has been found by experiment that the more accurately all the measurements necessary are made, in an experiment of this kind, the more nearly do the gain and loss of energy balance, so long as the body neither gains nor loses matter. That is to say, the law of the conservation of energy holds for men and animals. They do not obtain energy from any mysterious sources, nor do they convert it into any forms which cannot be reconverted into heat. The energy arises from the recombination of oxygen with carbon and hydrogen, from which it has been separated by plants. The carbohydrates, fats and proteins formed by the plant are largely eaten by animals, which use them partly for growth and repair, but mainly

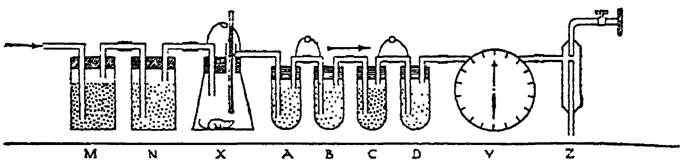


FIG. 20. Method of determining the gaseous exchange of a small animal. N, A, B and D contain pumice soaked in strong sulphuric acid to absorb water vapour. X contains a mouse, M and B a mixture of soda and lime to absorb carbon dioxide. Air is sucked through by the pump (Z) on the right, to which is attached a gauge (Y). The mouse therefore gets air free from CO_2 and H_2O. The H_2O breathed out by it is caught in A and B, its CO_2 in C, and any H_2O evaporated from C in D. Hence the increased weight of C and D gives the animal's CO_2 output, the increased weight of X, A, B, C and D together its O_2 consumption.

as a source of energy. A carnivorous animal obtains its energy second- or third-hand from the plant, but in the long run all animal energy, just like the energy derived from coal, is stored sunlight.

We can now consider the energy values of different foods, and the energy requirements of different classes of people. Foods consist of water, salts, carbohydrates, fats and proteins. Energy can be obtained from the oxidation of the latter three. Proteins are not completely oxidized by animals, so we have to deduct the energy value of the unoxidized remnant from that of the original protein. When this deduction has been made we find that the energy values are as follows:—

1 gram carbohydrate = 4·1 kilocalories.
1 gram fat = 9·3 „
1 gram protein = 4·1 „

That is to say, fat is more than twice as good a source of energy, weight for weight, as any other food. It must be remembered that while fatty foods such as butter and lard contain very little water, and bread, which is our greatest source of carbohydrate, contains only about 10 per cent; lean meat, though most of its solids are protein, contains 75 per cent of water. We obtain most of the energy we need from carbohydrates and fats. The proteins, though they also supply energy, are mainly required for the growth and repair of our bodies.

The accompanying table shows the energy values per pound of a number of foods, and the number of calories that could be bought for a shilling when this table was compiled.

Food.	*Kilocalories per lb.*	*Kilocalories per shilling.*	*Protein per cent.*
White Bread	1,200	5,760	8
Biscuits	1,900	1,750	10
Oatmeal	1,810	5,430	15
Sugar	1,815	6,400	0
Milk	314	1,260	3·3
Butter	3,490	2,090	1
Cheese (Cheddar)	2,080	2,500	28
Lard	4,090	4,260	0
Beef (round, lean)	650	650	20
Beef (rump, fat)	1,360	630	13

Food.	Kilocalories per lb.	Kilocalories per shilling.	Protein per cent.
Bacon	2,370	1,580	9
Herrings (fresh)	360	720	11
Potatoes	300	3,610	1·8
Cabbage	120	1,450	1·4
Apples	215	430	0·3

The energy requirements of a man or animal vary, like those of a machine, according to the amount of work he is doing, but, unlike a machine, an animal, even when resting completely, needs a considerable amount of energy, partly for internal movements, such as those of the heart, the gut, and the muscles concerned in breathing, partly, in the case of warm-blooded animals, to maintain the body-temperature. Above this minimum, additional energy is required according to the amount of work done. An individual muscle, say the biceps of the upper arm which bends the elbow, may have an efficiency as high as 40 per cent, that is to say it can turn into work nearly half the energy that it derives from food and oxygen, but if we consider the body as a whole the efficiency is a good deal less, since the heart has to work to supply the muscle with its blood, the lungs and gut to supply the blood with oxygen and food, and so on, in which process much potential energy is converted into heat by internal friction. As a matter of fact, we find that the efficiency of the body as a whole is never more than about 25 per cent. Even this, however, is greater than the efficiency of any heat engine of the same weight. The advantage of mechanical over animal power is not that the machine is more efficient, but that its fuel is cheaper, and that it does not waste energy while it is not working.

If we take a man's output of energy per minute when lying down as 1, it will be about 1·4 when he is standing, 4 when he is walking at three miles an hour or doing moderate work with his arms, 10 during fairly hard work, 15 during the most violent exertion of which he is capable for any length of time, and over 50 during very violent work, such as a hundred-yard sprint. His intake of oxygen and output of carbon dioxide vary directly with the amount of energy set free, and if he is to keep up his weight he must eat enough food per day to supply the energy which he is liberating. The following table shows the

energy requirements in kilocalories per day of different workers each weighing about 65 kilograms (10 stone):—

Profession.	*Energy needed in food.*
Clerk	2,410
Tailor	2,510
Cobbler	2,940
Metal worker	3,290
House painter	3,500
Carpenter	3,550
Stonemason	4,660
Woodcutter	5,400
Cyclist (racing for 16 hours)	10,240

The cyclist probably could not eat the required amount of food per day, and so had to use up his own fat as a source of energy.

The energy output of a resting warm-blooded animal (mammal or bird) is proportional to its surface, not to its weight or volume. Thus if two dogs are of the same shape, but one twice as long, high and broad as the other, it weighs eight times as much, but needs only four times as much food per day, as its surface is only four times that of the small dog. Thus children need a great deal more food per pound of their own weight than do adults for energy production alone, besides their requirements for growth. Similarly if we compare a large cart horse weighing a ton with a ton of men (13), a ton of fowls (500), and a ton of mice (55,000), their food requirements will be proportional to their total surfaces, and the men will need 3·7 times as much energy per day when at rest as the horse, the fowls 8 times, and the mice 25 times. This law does not hold for "cold-blooded" animals.

Although in the long run the oxidation of food is our only source of energy, yet a muscle or gland can work for a short time without any oxidation. The immediate source of muscular energy seems to be the breakdown of a compound of sugar and phosphoric acid into lactic and phosphoric acids. This chemical reaction is used as a source of work, but to put its products together again so that they can furnish more work, sugar must be oxidized, so a muscle cannot work for long without being supplied with oxygen. In a sprint of 100 yards the leg muscles work faster than we can supply them with oxygen, and are very short of it at the end. So if in running a quarter-mile, a runner sprinted during the first 100 yards, his muscles would be short of

oxygen for the rest of the race, and would work inefficiently. It is better to put off the sprint to the end and run less rapidly at first, so that the muscles are able to get all the oxygen that they need.

Our energy requirements can be made up in various ways, just as a fire may burn coal, wood or peat. Thus a diet of 135 grams protein, 80 grams fat, 500 grams carbohydrate will furnish 3,350 kilocalories, but within fairly wide limits we can replace one food by another yielding the same amount of energy. Fifty grams of the protein could be replaced by 50 of carbohydrate or 21 of fat without reducing the protein intake below what is needed for repairs. But we cannot make out a dietary on a basis of energy alone. The tissue proteins are always breaking down, and need a certain minimum of protein food to build themselves up again; whilst a growing child, a pregnant or nursing woman, or a man recovering from illness or building new muscle during training, needs more than this. All kinds of protein are not of equal value. A vegetarian, if he does not take milk or cheese, must eat more protein than a meat-eater to keep in health, as vegetable proteins are generally less digestible than those of animals, and on digestion yield products which are not in the best proportions for building animal tissues.

We also need various inorganic substances besides water, for example, calcium salts for our bones, iron salts for our hæmoglobin, sodium chloride for our sweat. Finally, our diet must contain small quantities of at least four, and probably five or six, different organic compounds generally called vitamins. We do not know the exact composition of these, though we know a good deal about them, for example, that one is a base (like quinine or adrenaline), two others soluble in oil like a fat or wax, and so on. Vitamin A is a fat-like and soil-soluble substance found in leaves and many natural fats and oils. It is necessary for growth, and a shortage of it leads to eye troubles and loss of immunity to various diseases. B is easily soluble in water and probably a base. It is found in many living tissues, notably yeast and the embryos of cereal grains. Its absence leads to a failure of growth, and to affections of the nervous system. C is water-soluble and easily destroyed by oxidation. It is found especially in fruit and leaves. Its absence leads to scurvy. D has properties and a distribution similar to those of A. Its absence leads to rickets and bad teeth, but it is formed whenever an at

present unknown precursor, related to cholesterol, and a constituent of most cells, is acted on by ultra-violet radiation. So a plentiful exposure of the skin to sunlight will make up for a deficiency of it. E is an oil-soluble substance found especially in wheat embryo. Its absence causes sterility, but not ill-health. This list is probably not complete. Some of the vitamins, especially C, are liable to be destroyed by over-cooking, others are often removed with the bran in milling grain, so that human diets are often short of one or another of them. Most plants can make some or all of them, and some animals do not require them all.

To sum up, a complete diet must include inorganic substances, organic bodies which can be oxidized to yield energy, and a number, probably about twenty, of different organic compounds which the animal body cannot itself build up.

CHAPTER FOUR

TRANSPORT IN THE BODY

ENERGY IS CONSTANTLY being liberated in every part of the body as the result of chemical changes, so we must study the methods by which food and oxygen are distributed, and waste products removed. We may begin with the exchange of gases, which in our case we call breathing. In simple animals like jelly-fish and many worms there are no special organs for this purpose. Dissolved oxygen soaks through their skins from the water in which they live, and dissolved carbon dioxide soaks out. In somewhat more complicated creatures like the earth-worm there is a special fluid, the blood, one of whose functions is to carry oxygen from the skin to the internal organs, and carbon dioxide back. In the most advanced water-dwellers we find special tufts of thin skin, the gills, into which blood is pumped by a heart or hearts, so as to expose it to water with which it may exchange gases. Gills may be naked, as in the young tadpole, but usually, as they are very delicate, they are protected by lids or pouches, as in fish or lobsters, where they lie behind the head on each side. In air-breathing animals there are two quite different kinds of breathing organ. In insects and spiders, air is carried to every part of the body by tiny branching tubes called tracheæ, which open by numerous pores, mainly on the sides of the abdomen (Fig. 21). In air-breathing vertebrates and molluscs the blood is exposed in the lungs to air which is continually renewed by the act of breathing. Some animals combine several methods. Thus a frog can use its skin alone for breathing so long as it does not need much oxygen, but it normally employs its lungs as well.

The human lungs are elastic organs of a spongy texture, consisting of millions of very small cavities which open into stiff tubes called bronchi. These in turn open into the windpipe in the front of the neck. Since air cannot enter the space between the lung and the chest wall, the lungs expand when the chest is expanded. This can happen in two different ways. In the first place the diaphragm, a sheet of muscle separating the chest and belly, and bulging upwards into the former, may contract and force the contents of the belly downwards and out-

wards. This pulls the bases of the lungs down, and draws air into them. Or the muscles which lie between the ribs may contract so as to bring the ribs, which normally slope downwards, into a more horizontal position. The breast-bone is thus pushed away from the vertebral

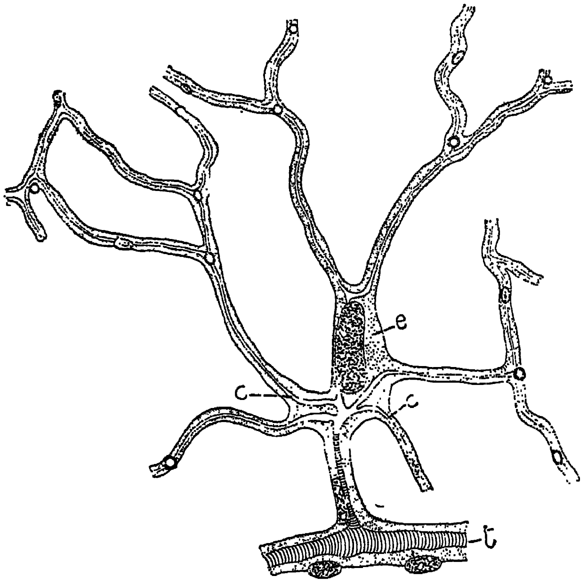


FIG. 21. Final ramifications of tracheæ (tracheoles) in a caterpillar. *t*, a small trachea, prevented from collapsing by its spirally wound chitinous thickenings. *e*, a cell in which connexion is made between a trachea branch of smallest size and a number of tracheoles, *c*. These contain air-channels less than 1μ in diameter, which run within the bodies of elongated cells, whose nuclei are seen in the figure, and require no special strengthening in their walls. (From Imms, after Holmgren.)

column, while at the same time the diameter of the chest from side to side is increased, and the lungs expand to fill the extra volume. Muscles acting in the opposite direction force the air out again if necessary; generally the elasticity of the lungs is sufficient. Thus the air to which the blood in the lungs is exposed is constantly being changed. The inspired air contains 21 per cent of O_2 and only 0·03 per cent of CO_2, whilst the expired air (after being dried) contains about 17 per cent

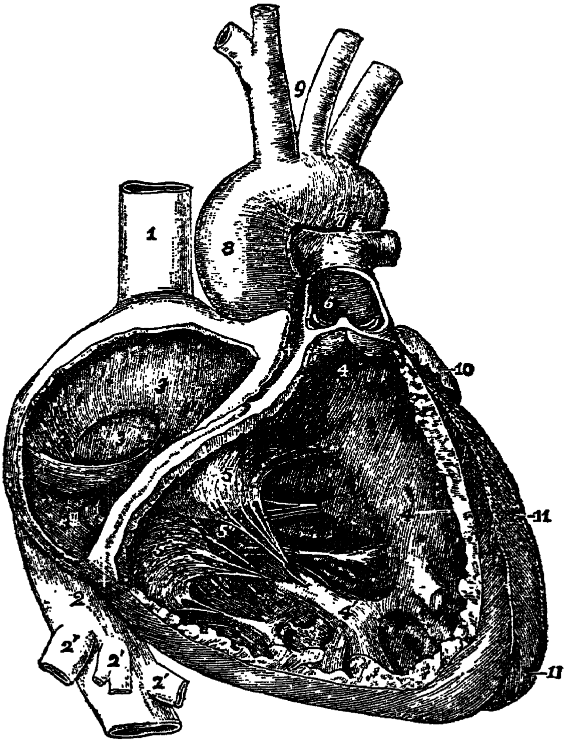


FIG. 22. A human heart seen from the right, with right auricle and right ventricle opened. 1, anterior (superior) vena cava; 2, posterior (inferior) vena cava; 2′, hepatic veins; 3, right auricle; 3″ is just to the left of the aperture of the coronary vein, which returns blood from the substance of the heart; 4, 4, right ventricle; 4′, one of the papillary muscles, attached by chordæ tendineæ to 5, 5′, 5″, the tricuspid valve between right auricle and right ventricle; 6, window cut out to show cavity of the pulmonary artery, at whose base three semilunar valves are seen; 7, ductus arteriosus, derived from part of the embryonic arterial arch system, and connecting pulmonary artery with 8, the aorta; 9, arteries to head, neck and fore-limbs; 10, part of left auricle; 11, part of left ventricle. (Allen Thomson.)

of O_2 and 3 per cent of CO_2. To understand how this change occurs we must study the circulation of the blood.

The blood flows to and from the heart, as we have seen, through a closed system of tubes known as arteries, veins, and capillaries. It leaves the heart by the arteries, which are comparatively thick-walled, and seldom near the surface, and returns by the veins, which have thinner walls, and often lie just below the skin. It passes from the arteries to the veins by the capillaries, which are too small to be seen with the naked eye, but are found in almost every tissue. The most easily felt arteries in man are those of the wrist and temple, the most easily seen veins those on the back of the hand and foot. Finally, the heart, which pumps the blood round, is a hollow muscle with four chambers, lying between the lungs, and about as large as the two fists together. A diagram of the course of the circulation in man will be found in Fig. 23. The blood from all parts of the body except the lungs enters the heart from behind, near the right-hand top corner, and flows into a chamber called the right auricle. This contracts rhythmically (the average rate in a grown man at rest is about seventy times a minute) and forces its contents into a thicker-walled chamber lying below it, the right ventricle. As soon as this is full it contracts in its turn. The blood is prevented from returning into the auricle by a valve, called the tricuspid. It therefore finds its way out through the pulmonary artery, which leads it to the lungs. The semilunar valves at the base of the artery prevent it from flowing back into the ventricle when this relaxes at the end of its stroke. In the lungs it has to pass through capillaries in the walls of the air sacs, so that it is only separated from the air by a very fine membrane, and can easily lose its carbon dioxide and take up oxygen. It returns from the lungs by the pulmonary vein, this time to the left auricle, which contracts at the same time as the right auricle, and fills the left ventricle. The left ventricle, which is assisted by valves not unlike those on the right side of the heart, forces the blood into the largest artery, an elastic tube called the aorta, from which it is distributed all over the body by the other arteries (Fig. 22).

One way of forcing it round through the narrow capillaries would be to have a cistern at the top of the head from which it flowed down again, but this arrangement would clearly not work when its owner lay down. In reality, a fairly steady pressure is kept up by the fact that

the walls of the aorta and the arteries are always stretched, and continue to squeeze the blood along between the strokes of the ventricles. The pressure in man is about that of a column of blood 1·7 metres high, i.e., equal to the head of blood which would be obtained from a cistern 1·7 metres above the heart. The heart of a grown man at rest delivers about 8 litres per minute, or just over 100 cubic centimetres per beat. During exercise the heart may deliver three or four times as much per minute, mostly as the result of an increased number of beats per minute. The beat of the heart which is felt below the fifth rib on the left side is due to the left ventricle striking the wall of the chest each time it contracts and stiffens.

The blood is squirted along the arteries at a rate which may be as high as 50 centimetres a second, and each fresh wave causes a pulse in the artery. If an artery is cut, the blood comes in a series of spurts from the side nearest the heart, and can be stopped by pressure on the heart side of the cut. It is easy (and safe) to stop the pulse in the wrist by pressing on the same artery higher up, either inside the elbow or inside the upper arm just below the armpit, where it can be felt.

The blood flows through the capillaries very slowly, at about half a millimetre per second. Their average length is about a millimetre, while their diameter may be less than 0·01 millimetre. Their very thin walls allow water, gases and dissolved substances to be exchanged between the blood and the tissues with great ease (Fig. 24).

From the capillaries the blood oozes gently into the veins. They have no pulse, and a comparatively small pressure and rate of flow. A cut vein bleeds steadily and the flow can be stopped by compressing the side away from the heart. The flow of blood in the veins is assisted by the presence of valves in them, which only allow it to move towards the heart. If the finger tip be run along one of the veins of the fore-arm away from the heart, the vein will dilate on the heart side of each valve. When therefore the contraction of various muscles squeezes the veins, the blood can only flow towards the heart. If a man stands quite still the blood tends to accumulate in the veins of his legs, and he is liable to faint from failure of the supply to his brain. When he starts walking the blood is at once squeezed out of these veins.

The only veins in man which do not lead straight back to the heart are those from the digestive canal and some other abdominal organs,

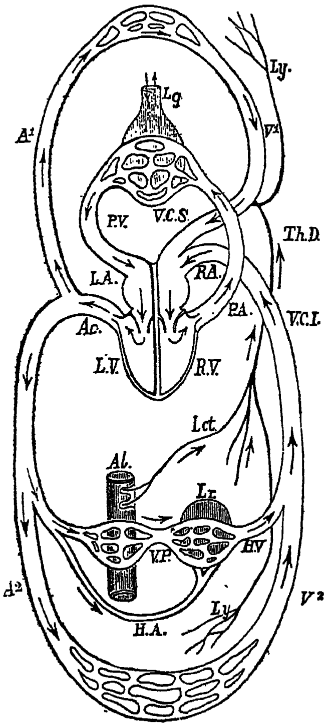


FIG. 23. Diagram of the course of the circulation in man. The blood entering the right side of the heart by the main vein flows into *R.A.*, the right auricle; thence, through a valve, into *R.V.*, the right ventricle, which pumps it, through a valve, down *P.A.*, the pulmonary artery, to the lungs, *Lg*. The blood here flows in capillaries, and is then gathered up into the pulmonary vein, *P.V.*, and taken to the left side of the heart, entering the left auricle, *L.A.*, then (through a valve) the left ventricle, *L.V.*, and by this being pumped out (again through a valve) into the aorta, *Ao.* Some of the blood (A^1) goes to the head and anterior extremities, whence it is returned by the anterior venæ cavæ (V^1), into which discharges the main trunk of the lymphatic system, the thoracic duct (*Th.D.*). The rest (A^2) goes to the trunk and hind-limbs. That which supplies the digestive tube (*Al.*) passes to the liver (*Lr.*) by the hepatic portal vein (*V.P.*); the liver also receives arterial blood direct by *H.A.*, the hepatic artery. The hepatic vein, *H.V.*, joins the veins from the other posterior regions, V^2, and flows to the heart in the inferior vena cava, *V.C.I.* *Lct.* denotes the lacteal lymphatic vessels from the intestinal wall, *Ly.* ordinary lymphatics. (Huxley, *Lessons in Elementary Physiology*, 1915.)

which pass into the liver. Here, as we shall see later, the food absorbed by the blood from the gut is dealt with (Fig. 23). As the liver needs oxygen, it has also a supply of fresh arterial blood.

In most other animals the circulation is somewhat different. Thus in a fish the blood only goes once through the heart in a complete journey, instead of twice, and it all passes through the gills before going on to the tissues. In the frog, in keeping with its two ways of breathing, we have a condition almost half-way between that found in fish and men (p. 123).

We must now consider how the blood acts as a carrier of oxygen and carbon dioxide. Water at body temperature will only take up one two-hundredth of its volume of oxygen from air; if the blood were no better than this we should need a heart working forty times as fast as the one we have. Actually the oxygen is carried round in loose chemical combination with a body called hæmoglobin. This is a protein, but contains iron as well as the usual carbon, hydrogen, oxygen, nitrogen and sulphur. It is of a purple colour, but becomes red on combining with oxygen, which it readily takes up from the air. Thus the blood in the veins is purplish, but if exposed to air either in the lungs or by opening a vein, it at once becomes red. The hæmoglobin which it contains enables blood to hold eighteen volumes of oxygen per cent, which is six-sevenths of the amount contained in the same volume of air, and about forty times what the blood could carry without hæmoglobin. Since blood carries dissolved solids as well as gases, a single set of capillaries supplies the tissues with all that they need for activity, growth and repair, besides removing most of the waste products. The carbon dioxide produced in the tissues is mainly carried, not in solution as such (CO_2), but in combination as sodium bicarbonate ($NaHCO_3$).

If we look at a drop of blood under a microscope we see that it consists of a clear fluid full of little reddish-yellow bodies about 0·007 millimetre in diameter, shaped like a round biscuit, with a depression on either surface. They can just be seen with a powerful hand-lens. A cubic millimetre of blood contains about five million, and, as a man has about 4 litres of blood, the total number in his body is about 20 million million, or far more than the number of men who have lived since history began, or probably at all. Their total surface is about

1,500 times the surface of the body. All the hæmoglobin of the blood is contained in them, and they therefore carry round the oxygen from the tissues. Their huge surface area renders this exchange easy. They are cells which have lost their nucleus and are therefore not fully alive,

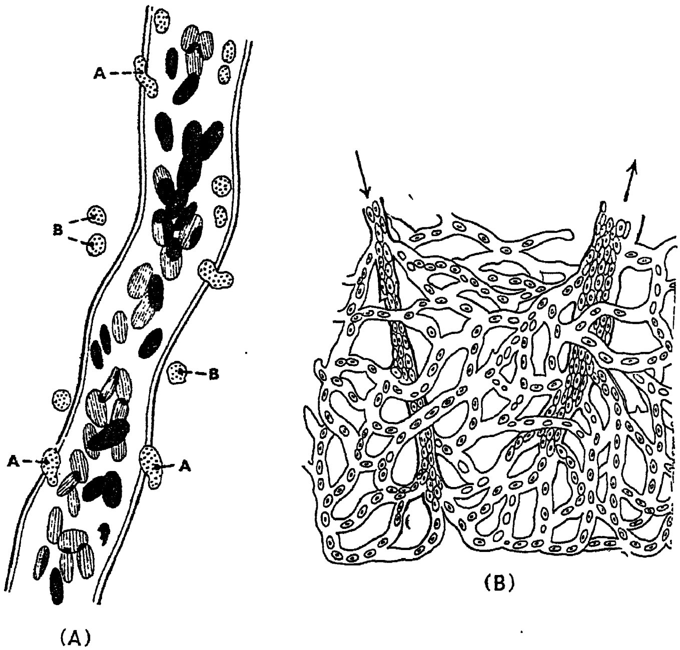


FIG. 24. (A) A large capillary vessel (from the mesentery of an anæsthetized frog) showing the migration of white blood corpuscles out of the vessel as a result of irritation caused by several hours exposure to air. *a*, *a*, leucocytes in the act of passing through the wall of the capillary; *b*, *b*, leucocytes which have passed right out (Frey). (B) A small arteriole (left) and venule (right), with a network of capillaries connecting them, as seen in the web of a frog's foot under a low magnification. (After Allen Thomson.)

but act as passive carriers of oxygen. They are always being produced in large numbers in the bone-marrow, and destroyed in the spleen and liver when worn out.

For every 500 or so of these red corpuscles there is one white corpuscle. Those shown in Plate 12 have been stained to show their

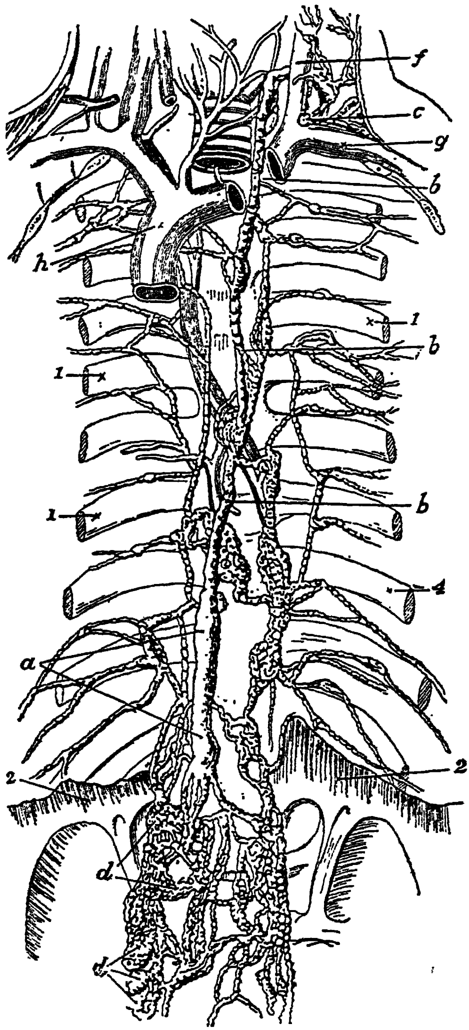


FIG. 25. Ventral view of the human thoracic duct (*a*, *b*). It is seen to be connected with other lymphatic trunks and glands (e.g., those in the lumbar region, *d*), and to open into the junction of the left jugular (*f*) and subclavian (*g*) veins at *c*. It lies just ventral to the spinal column, on either side of which are seen portions of the ribs (1). *h*, anterior vena cava, just anterior to which, is a piece of the windpipe. (Huxley, *Lessons in Elementary Physiology*, 1915.)

structure. They are true cells with nuclei, and some of them are capable of active movements. There are at least six different kinds with different functions, mostly of a protective character. Thus one kind eat up parasites found in the blood, another kind burrow through the walls of capillaries in inflamed areas, and remove dead or injured tissue and disease germs, often forming collections of "matter" or pus (Fig. 24 and Plate 12). Others produce substances which kill disease germs, and so on. The blood also contains non-cellular bodies called platelets, which are smaller than the corpuscles and are concerned in clotting and in immunity; there may also be tiny drops of oil after a fatty meal.

Besides the blood-vessels, all vertebrates possess another system of vessels which open into the veins, but contain clear fluid called lymph. The lymphatic vessels slowly drain away fluid from the spaces between the cells. On the course of the vessels the fluid passes through small lymph-nodes or glands, which may be felt under the skin in the neck, armpit or groin, before entering the blood. The lymph contains white corpuscles which are largely produced in these glands, and abnormal bodies from the tissues are dealt with in them. Thus if the arm is inflamed, the lymph-nodes of the armpit are generally enlarged, as they are busy destroying poisons or bacteria from the inflamed tissue. The lymphatics also play a part in digestion, which we shall study later (Fig. 25).

We must now see how the cells obtain the foodstuffs which they require. In simple animals such as polyps every cell is so close to the digestive cavity that it can obtain food thence directly. In most higher animals, however, the cells which line the alimentary canal and its glands are highly specialized for the purpose of breaking up the foodstuffs into soluble forms and passing them rapidly into the blood or other body fluids. This process is called digestion. A few internal parasites like the tapeworm have no gut, but absorb their food through their skin, relying on their host to break it up for them.

The course of digestion in man is as follows. The food is chewed in the mouth, where it is also moistened by saliva, a fluid secreted mainly by three neighbouring pairs of glands. Two pairs of these lie between the tongue and the lower jaw, the third pair (whose inflammation causes mumps) lie below the external ear, mainly inside the lower jaw bone. Besides moistening the food, saliva contains an enzyme, ptyalin,

which breaks up starch into an easily soluble sugar called maltose.

Enzymes play a much larger part in digestion than do mechanical processes. Each digestive enzyme is a definite substance with the property of bringing about, or enormously speeding up, a particular chemical reaction. Pepsin from the stomach will split up half a million times its weight of protein, but will not alter starch or fat. So delicately is an enzyme adjusted to the substrate on which it acts, that as most food molecules are asymmetrical (as we know from their rotation of the plane of polarized light and their asymmetrical crystals) so are the enzymes that act on them. Enzymes have been compared to keys which open certain locks only. But they are like "Yale" rather than ordinary keys. For we can make in the laboratory a sugar or peptide (part of a protein molecule) which only differs from the natural variety in that its molecules are related to the natural molecules as a left hand to a right or an object to its image in a mirror. Enzymes will not act on these artificial substances, though they digest their mirror images which occur in nature. So Alice, who went through the looking-glass in the story, could not have digested the looking-glass proteins and carbohydrates. She would have had to get her energy from fat and alcohol, whose molecules are symmetrical, and would finally have died of protein starvation.

Enzymes are not alive, and can still work when removed from the body; but they are generally destroyed by boiling. The action of ptyalin can easily be shown. A solution of boiled starch gives a blue colour with iodine. If saliva is allowed to act on it for a few minutes at body temperature or a few hours in the cold, the starch is broken down to sugar and loses this property. If the saliva is first boiled no change occurs.

When the food is swallowed, it is passed into the gullet or œsophagus. To get there it must pass over the mouth of the windpipe, and when any falls down this we choke. To prevent this, the breathing is stopped while we swallow, and the cartilages at the top of the windpipe which are concerned in voice production are brought together so as to close the top of the larynx. It is further protected by a cartilaginous lid at the back of the tongue called the epiglottis, which is pressed backwards over it by the food during swallowing. The movements of the laryngeal cartilages can easily be felt. As the food leaves the

mouth it passes out of the control of consciousness and will. The movements of our digestive canal, except at the two ends, are carried

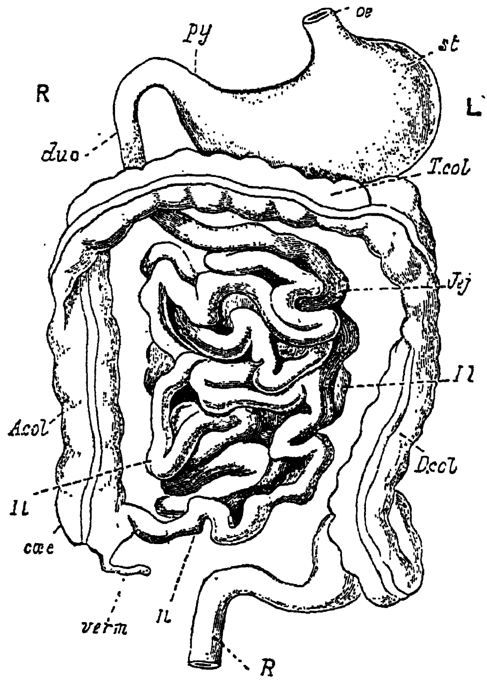


FIG. 26. The abdominal portions of the human digestive tube, ventral view. R, right; L, left sides of the body. *oe*, gullet (œsophagus). *st*, stomach. *py*, aperture of stomach into small intestine (pylorus). *duo*, duodenum, opening into the much-coiled remainder of the small intestine (*Jej* and *Il*). This opens into the large intestine, with its cæcum (*cæe*) and vermiform appendix (*verm*). It is divided into colon, ascending (*A.col*) and descending (*D.col*), and rectum (*R*). (Huxley, *Lessons in Elementary Physiology*, 1915.)

out by smooth or involuntary muscle and are controlled by a special part of the nervous system over which the mind does not preside. The food or drink on leaving the mouth is seized by the smooth

muscle of the œsophagus, which contracts behind it and relaxes in front, thus passing it rapidly down into the stomach. Owing to this gripping action one can eat or drink while standing on one's head.

The human stomach (Figs. 26, 28) is a bag of smooth muscle lined with a membrane consisting mainly of microscopic glands (Fig. 27). When expanded it will generally hold about 2 litres. The gastric juice is a clear fluid containing about ½ per cent free HCl, and several enzymes, of which the most important is pepsin. In presence of acid (though not in a neutral or alkaline fluid), pepsin causes proteins to break up into bodies called peptones and proteoses, which have very much smaller molecules than the proteins from which they are derived, and are more soluble. Some carbohydrates are attacked by the hydrochloric acid. Thus each molecule of cane sugar is split into one of glucose and one of fructose, and inulin, a starch-like body found in many plants, is broken up into fructose. Fats are less affected in the stomach.

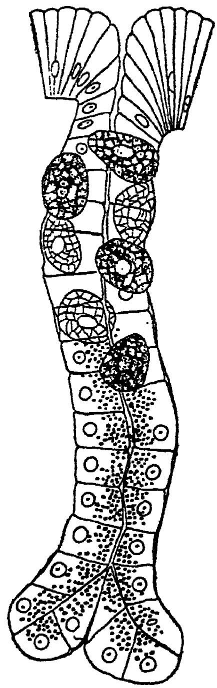


FIG. 27. A simple gland from the stomach of a mammal (a bat). The narrow duct opens above into the cavity of the stomach, among columnar cells. The main part of the gland is a simple tube, formed of a single layer of cells; these secrete pepsin. A few darker stained cells are seen near the outer side of the tube; these probably secrete hydrochloric acid.

A meal remains in the stomach for a time—generally between one and four hours—which depends on the nature and quantity of the food taken. All this time the muscular walls of the organ are contracting in such a way as to mix the food thoroughly with the gastric juice. Hardly any absorption occurs in the stomach. When its contents are fully mixed the muscular ring surrounding the lower orifice of the stomach, the pylorus, opens,

and a jet of its contents is squirted into the duodenum, the top portion of the small intestine. After a heavy meal the stomach may take several hours in emptying itself.

The human small intestine is a tube about 6 metres long and 3 centimetres in diameter when relaxed (Fig. 26). It is lined by fine projections of the mucous membrane, the villi, which give it a velvety

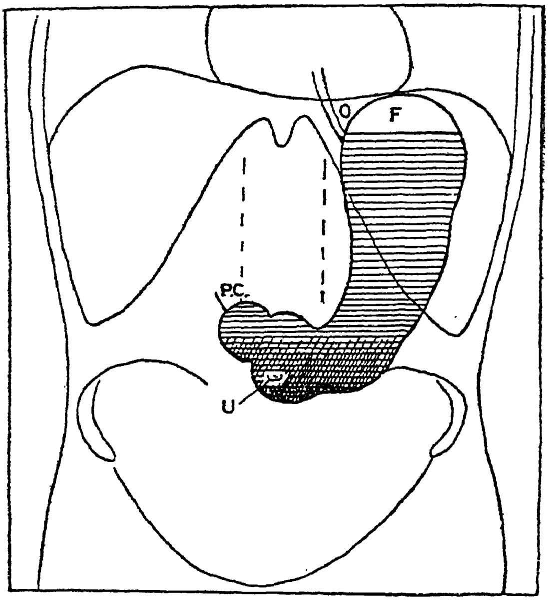


FIG. 28. The position and shape of the moderately full human stomach, as revealed by X-ray photography after a meal mixed with oxychloride of bismuth, which is opaque to X-rays. O, gullet (œsophagus); F, fundus of the stomach (containing air); P.C., pylorus of stomach, opening into the small intestine; U, position of the umbilicus (navel) on the surface of the body. The dotted lines indicate the position of the backbone.

texture, and increase tenfold the surface available for absorption. Between the bases of the villi are the mouths of numerous microscopic glands, and just beyond the pylorus open the ducts of two large glands, the liver and pancreas. The liver, among its other functions, secretes bile. This contains substances which have the property,

possessed in a less degree by soap, of lowering the surface tension of water in which they are dissolved. Drops of oil or melted fat tend to join up so as to have as small a surface as possible. This tendency of the surface to shrink is prevented by the bile in the intestine, so when fat drops are broken up there they do not coalesce again, but form a milky emulsion. Hence the fat-splitting enzyme made in the pancreas can act on a vastly greater surface of fat than would otherwise be available. A man with jaundice from a blocked bile duct can digest milk, whose fat is already broken up, but not suet or butter, which form big drops. The bile also contains pigments formed from the hæmoglobin of worn-out red corpuscles. These are excreted in the fæces and give them their yellow colour. In jaundice the bile duct is blocked, and accordingly the skin becomes yellow and the fæces white. Bile is stored in the gall bladder till required.

The pancreas secretes a juice containing a number of enzymes. One of these, like ptyalin, breaks down starch into maltose. Others break down maltose to glucose, and lactose (milk sugar) into glucose and galactose, a very similar substance. Another breaks down fat into glycerol and fatty acids, which partly combine with alkali to form soap. In every case the molecules formed will pass more easily through a membrane than those of the food. If the juice contained a protein-splitting enzyme it would probably digest the pancreas itself and its duct. However, it contains a substance which, on mixing with the secretions of the intestinal glands, yields trypsin, an enzyme which attacks proteins and the products of peptic digestion, breaking them down into amino-acids. These enzymes will not act in an acid fluid, so the bile and pancreatic and intestinal juices have to contain enough sodium bicarbonate to neutralize the acid of the gastric juice.

The secretion of the intestinal glands, besides the substance which helps to form trypsin, contains an enzyme which will break down peptones, though not whole protein molecules, into amino-acids. There are also enzymes which break down milk-sugar and cane-sugar to sugars containing only six carbon atoms.

So far as we know, no animal more complicated than a snail produces an enzyme which will break up cellulose. But grass consists very largely of cellulose, and to digest it hoofed animals and other plant

eaters employ bacteria which grow in their digestive canal. In cud-chewers like the cow and sheep these bacteria live in special compartments of the stomach; in the horse in the large intestine, which may have a capacity of 200 litres. The bacteria can get very little oxygen, so they cannot oxidize the cellulose, but they turn a good deal of it into methane, which is wasted, and leave much undigested. The rest, however, is broken up into small molecules which the animal can absorb. In man, cellulose is not digested, but it is useful in giving bulk to the fæces and preventing constipation, which easily occurs when the food leaves no indigestible residue.

The food is thus broken up into easily soluble constituents, and is ready to be absorbed. This is done by the epithelium of the small intestine. The passage through is not a mere filtration. For example, the blood contains one part of sugar per thousand, and if sugar merely filtered across from gut to blood, it could never quite disappear from the gut as it in fact does. Actually, during the absorption of food, the absorptive cells perform work, for which they need an extra supply of oxygen.

The fats are, in part at least, put together again from glycerine and soap, and passed as a fine milky emulsion into the lacteals, as the lymphatics of the small gut are called. These join together to form the thoracic duct (Fig. 25), which runs up through the chest and empties into the jugular vein at the base of the neck. The blood may be noticeably milky after a heavy meal of fat. The rest of the products of digestion are passed into the capillaries, and dissolved in the blood.

All the veins from the gut run to the liver (Fig. 23), and here the food is further dealt with. Thus sugar, if not needed immediately for oxidation, is stored as a starchy body called glycogen, discovered by Claude Bernard, and gradually liberated as required later on (*see* Chapter Eight). Some of the sugar and most of the fat are stored elsewhere. Part of the sugar is stored as glycogen in muscles, but much of it is made into fat and stored under the skin and round some of the internal organs, along with fat from the food. In the frog fat is stored in special fat bodies. The stored glycogen is later split up into glucose for use in the body by an enzyme, which continues to work after death, and the sugar thus liberated gives liver its well-known sweet taste. Absolutely fresh liver is not sweet. Again, ammonia, which is

formed in the digestion of many proteins, is, in the liver, mostly combined with carbon dioxide to form urea ($2NH_3 + CO_2 = CON_2H_4 + H_2O$). Urea is an innocuous body, but ammonia poisonous if it gets to the brain, so that if the blood from the gut is short-circuited into the vena cava instead of going into the liver, a heavy meal of meat may cause convulsions. The liver also deals on the same sort of lines with any excess of amino-acids in the blood and with various poisons; its most important function is thus the regulation of the blood's composition, and not the secretion of bile. During starvation the body lives on its stores of fat, and the liver takes on the new duty of converting the stable fats such as those of suet into oils like that of linseed, which are very easily oxidized.

The unabsorbed residue of the food from the small intestine passes into the large intestine, where it remains in man for a day or so, and is acted on by bacteria. These are of little or no value to man, though very valuable to some animals. In man little but water is absorbed there. By this removal of water the bulk of the waste food is reduced by about nine-tenths. The large intestine also excretes poorly soluble salts, such as calcium phosphate, from the blood. These would clog up the urinary passages if they were excreted by the kidneys.

The active tissues take oxygen, sugar, fat and amino-acids from the blood, and use them for oxidation, growth, and repair. Into the blood they empty waste products, of which the most important are water, carbon dioxide and urea, but other soluble waste products of protein metabolism include sulphuric and phosphoric acids, creatinine and uric acid. The last two contain C, H, O and N. They are all excreted by the kidney except the carbon dioxide and some of the water, which go out by the lungs, and, in the case of water, the skin.

The kidneys consist of a mass of tubules (Fig. 29) (about a million on each side in man) each beginning in a capsule containing a tuft of capillaries, and ending, after a winding course, in the central cavity of the kidney. The capillary tuft seems to act as a filter, and the fluid that soaks through it is blood minus corpuscles and minus a few of the large molecules, such as the proteins concerned in clotting. As this filtrate runs down the tubules, the cells lining them reabsorb valuable constituents of the blood, such as sugar, and probably add unwanted ones such as urea, ammonia, uric acid, creatinine and sulphates. The

urine trickles down the ureters into the bladder, whence it is emptied from time to time. An adult man produces on an average about 1·5 litres of urine per day, containing thirty grams of urea, fifteen of sodium chloride, and ten of other soluble waste products.

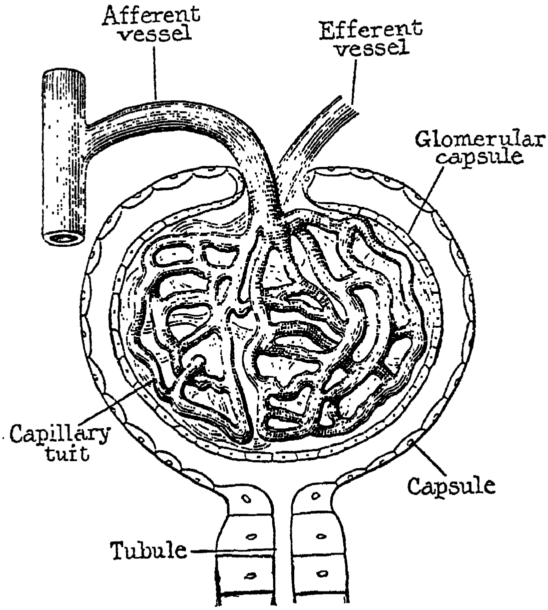


FIG. 29. Diagram of a Malpighian corpuscle in the human kidney. The end of the kidney tubule is thin-walled, and is dilated to form a capsule (Bowman's capsule). This is invaginated by the ingrowth of a small arteriole and venule, which break up within the inner wall of the invaginated capsule to form a network of capillaries or glomerulus.

The blood is thus the medium of exchange between the different parts of the body. The heart keeps it moving, the lungs and gut supply it with fresh oxygen and foodstuffs, other organs get rid of waste products, and all the tissues of the body take from it according to their needs. The life of every part of the organism therefore depends on an adequate supply of blood of proper composition.

CHAPTER FIVE

THE NERVOUS SYSTEM

THE ACTIVITIES SO FAR described may almost all be found in machines, but a complicated machine needs human control if the parts are to work harmoniously. The body to a large extent runs itself. The diaphragm and heart contract with the appropriate force and rhythm, the pancreas begins to secrete as food reaches the duodenum, and so on. But in many of our more complex activities, such as the movements of my hand as I write these words, consciousness plays a part. The chief agency in co-ordinating our actions is the nervous system. Many of its activities are unconscious: consciousness and will only play a part where our past experience is likely to be of value in influencing our behaviour.

The unconscious responses of the nervous system are called reflex actions, or reflexes; though of course it is also responsible for voluntary actions. The nervous system controls striped muscle, heart muscle, smooth muscle and glands, but with very few exceptions it is only the striped muscles that the will can influence, and even they are often moved by reflexes. In every reflex or voluntary action three organs are always concerned, first a receptor organ which is appropriately stimulated, then a longer or shorter path in the nervous system, and finally an effector organ. The latter is always a muscle or gland in man, though other animals have electric and luminous organs under nervous control. In the case of voluntary action the delay in the central nervous system may be very long, but there is always some external motive for a voluntary action. The nature of reflex and voluntary action will be made clearer by a few examples, tabulated on the following page.

It will be seen that all but the last are reflexes. The first three are entirely independent of will or consciousness. They are performed by smooth muscle. The fourth involves consciousness but not will. It can, however, be influenced by voluntary attention. The next four are performed by striped muscle, and are partly under voluntary control. The last is a very simple voluntary action. The line between reflex and voluntary action is not sharp. Only an experienced school-

Action.	*Receptor.*	*Effector.*
1. Speeding up of the heart on increasing its supply of blood (Chapter Seven).	Nerve-endings in right auricle.	Heart muscle.
2. Contraction of pupil in strong light.	Retina of eye.	Smooth muscle of iris.
3. Reddening of skin after a scratch.	Pain spots of skin.	Smooth muscle of small vessels which open.
4. Secretion of saliva on smelling food.	Olfactory organ in nose.	Salivary glands.
5. Knee jerk.*	Nerve-endings in tendon.	Extensor muscles of thigh.
6. Blinking on eye being struck at.	Retina of eye.	Eyelid muscles.
7. Breathing.	Respiratory centres in brain.	Muscles of chest and diaphragm.
8. Sneezing.	Nerve-endings in nose.	Muscles of chest and diaphragm.
9. Answering a bell.	Organ of Corti in ear.	Leg muscles.

master can tell voluntary from reflex coughing. It will be seen that the receptor organs are generally, but not always, sense organs, that is to say, their stimulation produces consciousness as well as reflex action.

We can learn a great deal about the properties of nerve by taking a muscle with its motor nerve out of a recently killed animal. If we stimulate the nerve by electrical or chemical means, or mechanically (e.g. by pinching), the muscle will contract. This irritability continues for many hours, though the muscle is very easily fatigued unless it has a proper oxygen supply. The muscle may be made to work a lever which writes on a moving sheet of paper, and the effects of different

* Sit down, cross the legs, and hit the tendon below the knee-cap. The extensor muscles of the thigh contract, and the foot flies up.

stimuli can thus be compared. We can also measure the heat or electrical changes produced. By such means we learn the following facts about nervous conduction.

Each fibre conducts independently of the others. It conducts not a steady stream, but a series of nervous impulses. An impulse is not an electric current, but an activity of the nerve fibre producing an electrical effect and a little heat as it goes along. It travels at about 30 metres per second or 70 miles per hour in man. Thus a man, hit by a car going at 80 miles per hour, will probably feel nothing because his brain is destroyed before any nervous impulses from his skin reach it. After the passage of an impulse the fibre needs a rest of one-thousandth of a second or more before it can transmit another. All impulses in the same fibre are normally of the same intensity. Thus, from this point of view, we may compare a nerve to a bundle of telegraph wires, down which electrical waves of the same intensity pass at varying intervals, but not to a bundle of telephone wires, in which the intensity of the waves is variable. Finally, the energy of a nervous impulse is so small that about four million impulses (which would take several hours to pass) would be needed to heat a nerve 1° centigrade.

A voluntary muscle responds to one nervous impulse by a twitch, to a rapid series by a steady contraction. A contracting human muscle is getting about forty-five impulses per second. The energy liberated in a gram of contracting muscle is several hundred thousand times greater than that in a gram of the nerve which supplies it. This ratio is about the same as that of the energy developed by a 30-h.p. motor car running for twelve hours, to that used by the man who turns the starting handle for a minute. Muscles can be made to contract by weak artificial electric currents as easily as by those produced by the nerve.

We are not yet sure of the details of how a muscle contracts, though it seems that the lactic acid formed causes microscopic fibrils to contract, as many proteins do when placed in weak acid. A muscle is not a heat engine, for it has a very high efficiency such as is only found in heat engines one part of which is very much hotter than the other. Its chemical energy is converted directly into work without first passing into heat. The actual process of contraction may have an efficiency of 90 to 100 per cent, but an amount of energy greater than the work

done in contraction is wasted as heat during the re-synthesis of the lactic and phosphoric acids, so that the whole process has an efficiency of only about 40 per cent. Moreover, a good deal of energy is needed for the extra breathing and heart action during exercise, besides the basal metabolism which goes on all the time. So, considered as a machine, a man never has an efficiency of more than 25 per cent. At best, he turns three times as much energy into heat as into work. Moreover, a muscle heats up while keeping up a steady contraction, as in standing, supporting a weight, or pushing at a closed door.

Striped muscles become quite flabby when their nerves are cut, but heart muscle and smooth muscle remain active. Striped muscles have probably only one set of motor-nerves which make them contract. Involuntary muscles have two sets: stimulation of one set causes increased activity, of the other set rest or lessened activity.

The effects of stimulating a nerve-fibre depend mainly on its connexions in the body, to some extent on the quantity and rhythm of the stimulus, but not at all on where in its course it is stimulated. These facts were first discovered by Müller in 1826. Thus a blow on the "funny-bone" or just above it is felt in the ring and little fingers because the nerve from them runs near the surface at this point, and irritation of the nerves in the stump of an amputated leg will give a man pain which he feels in toes that he may have lost forty years ago. Again, when the nerve to the face muscles has been destroyed, the power to move them may sometimes be regained by grafting the nerve supplying certain neck and shoulder muscles into the old track of the facial. But when connexion has been made, the patient, in order to move the face, must will to move the shoulder.

The most accessible receptor organs are those of the skin. They can easily be studied in an area where they are scattered, as on the side of the knee. If the skin is shaved we find that only parts round the hair roots are sensitive to gentle touch with a bristle. Each root is surrounded by a network of nerve-fibres which are easily stimulated. The small hairs act as levers, and render the "touch spots" more sensitive. In hairless parts, such as the palm, sole, and lips, there are special receptors for touch (Fig. 35). Similarly if we go over the skin with a warm blunt metal point, we find that warmth is only felt at a second set of points (not those sensitive to touch), cold at another set, and

pain at a fourth. Many areas on the thigh are quite insensitive to pain, as they have no pain spots. It is characteristic of receptor organs to be specially sensitive to one kind of stimulus, which may be physical, as with the skin organs, or chemical as with those of taste and smell. They will, however, generally respond to inappropriate stimuli, if these are strong enough. Thus mustard will stimulate first the heat and then the pain spots. A blow on the eye will make one see stars, and so on.

On the other hand each receptor organ, with the paths leading from it to the brain, can generally only give rise to one kind of sensation. This, however, depends on the part of the brain to which it leads, not on the organ which is stimulated. There is no fundamental difference in the nature of the impulses in different nerves, as there is in their effects. If we stimulate the optic nerve, even after the loss of the eye, we get visual sensations, and so on.

If we put the right hand into hot water, and the left into cold for a minute, and then both into lukewarm water, this feels cold to the right hand and hot to the left. This is characteristic of the senses. They tell us more about differences of intensity in their stimuli than about their absolute intensity. When we look at a candle in sunlight we find it hard to believe that we can see by it, or even be dazzled by it, at night. We go into a dark room, and see nothing at first, but soon adapt ourselves, and see the things in it instead of blackness. After half an hour in a sound-proof room one finds the noise of one's own heart and breathing unpleasantly loud: normally one cannot hear them.

The fineness of discrimination for touch depends mainly on the closeness of touch spots. Thus, on the palm, where they are very numerous, we can distinguish two points from one if they are 1 centimetre apart. On the back, where there are few touch spots, this distance must be increased seven times or more.

Under the skin are receptors of many kinds. Some respond to deep pressure, and others to pain, but when once the skin is cut through, most healthy tissues are almost insensitive to pain. They become tender, however, when inflamed. The gut and other hollow organs are insensitive to cutting or burning (stimuli to which they are not normally exposed), but very painful when stretched either by unusually bulky contents or unusually strong contractions of their muscles.

There are also receptors in muscles, tendons and joints. These send impulses to the central nervous system, which inform it of the relative positions and movements of different parts of our body. Receptors and nerves with this function are called proprioceptive, whilst those whose stimuli come from outside are called exteroceptive. Proprioceptive organs may affect the consciousness. Thus we can tell how

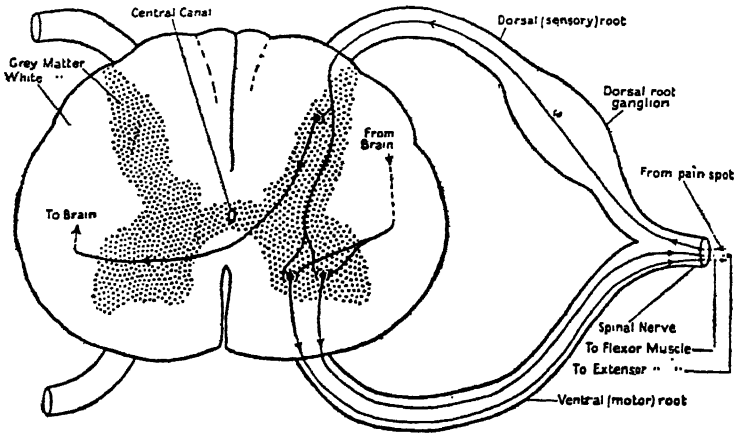


FIG. 30. Diagram to illustrate the course of nerve impulses concerned in a spinal reflex. The nerve-cell bodies are indicated as black dots, their fibres as lines. The grey matter of the cord is dotted.

much our knee is bent even with our eyes shut, owing to the joint organs, or how great a weight we are holding, owing to the muscle organs. But far more important is the aid they give us without our knowing it, in the co-ordination of muscular movement. If proprioceptive impulses cannot reach the brain from the legs, as happens in a disease of the spinal cord called locomotor ataxy, in which sensation is not lost, the patient cannot co-ordinate the movements or postures of his leg muscles. In walking he raises his foot too high and brings it down too hard. He cannot stand with his eyes shut. There is no weakness of the muscles, but they cannot be used properly, as the brain gets no information as to what they are doing except through the eyes.

The spinal cord consists of a central core of nerve-cells, called the grey matter, surrounded by millions of fibres mostly running lengthways, and called the white matter (Fig. 30). Both include a scaffolding

of supporting cells. Between each pair of vertebræ a nerve leaves the spinal canal on each side. It enters the spinal cord by a dorsal and a ventral root. The ventral root fibres go to muscles and glands, and are only traversed by impulses going outwards. The dorsal root consists of fibres carrying impulses from receptor organs to the cord. So if a dorsal root is cut we lose the capacity for feeling with a certain area of the skin, while injury to ventral roots leads to paralysis of muscles. But most nerves contain both sensory and motor fibres, so when a nerve is cut both movement and sensation are lost in the area which it supplies. The separation of the roots serves to bring all the sensory fibres to one cell area within the cord, all the motor fibres to another.

A nerve's only function is to conduct, but the spinal cord not only conducts impulses to and from the brain with its fibres, but gives rise to reflexes by means of its nerve-cells. This is shown by what happens when it is divided. If a man breaks his spinal cord in the neck, he dies because his breathing muscles are cut off from the brain, and get no nervous impulses to make them work. If it is broken lower down he may live for some time. He has absolutely no feeling in the parts of his body and no voluntary control over the muscles whose nerve supply comes from the part of the cord below the break. But if we examine him six months after the accident we find reflexes occurring in the lower part of his body. If, for instance, we pinch his foot it is drawn upwards without his knowledge or will. If the lower part of the cord is destroyed or the nerves to it cut, all reflexes cease. A great deal has been learnt about nervous activity from the study of spinal reflexes. They are easily studied on the carcass of a frog whose brain has been destroyed by poking a blunt wire into it from behind. If we irritate its skin its hind leg scratches near the place irritated, but its responses are clumsy, and it does nothing without some fairly violent stimulus.

Provided they are in nervous connexion with the brain or spinal cord, the muscles of a limb are never quite flabby. They are mostly in a state of gentle but steady contraction or "tone," so as to keep the limb in a definite posture. If then the knee is to be bent, as the flexor (bending) muscles of the thigh contract, its extensor muscles must relax. If they relaxed too little or too slowly there would be a strain and a waste of energy. If they relaxed too quickly or completely the

movement would proceed too far, and the knee joint might be dislocated. Exactly the same applies elsewhere. Almost every muscle in the body, those of the trunk, jaws and eyes, as well as the limbs, has an antagonist, and arrangements must be made for one to relax as the other contracts. As there are no inhibitory nerves to striped muscles, this can only be done by inhibiting or switching off the activity of those cells in the central nervous system which are sending impulses to the muscle which has to relax.

Fig. 30 gives an idea of some of the connexions concerned in a simple spinal reflex. An impulse enters the cord through a fibre in a dorsal root from a pain spot in the foot. The fibre divides and its branches end near nerve-cells in the grey matter. One of these cells is represented sending a fibre to a flexor muscle of the knee, another sends a fibre to an extensor. When the pain spot is stimulated the impulses passing along it cause more nervous impulses to be generated in the cell connected with the flexor muscle, less in that connected with the extensor, so the knee tends to bend, and the foot to be withdrawn. Actually things are far more complicated. Stimulation of a single pain spot will only cause movement after a long time or never, and, if movement occurs, hundreds of nerve-fibres will be conducting impulses at once. To get a prompt movement one must stimulate a number of spots or fibres from them at once, as when one treads on a hot coal. Though the type of connexion shown in the figure has actually been observed with the microscope, in most reflexes the excitation has to pass through several neurons before it reaches the cell whose axon is the nerve fibre to the muscle or other effector.

We must now study the function of the spinal cord in conducting nervous impulses in both directions between the body and brain. In a mixed nerve like the sciatic in the thigh, all sorts of fibres with different functions run together. Some are carrying impulses to the muscles, others from the skin and deep receptors. As they enter the cord they are sorted out according to which way they conduct, and later on a further sorting process occurs. For example, the impulses which on reaching the brain give rise to sensations of temperature, run up the spinal cord by a different path from those which give rise to sensations of touch.

These paths have been located by several different methods, which

have also been applied to the study of the brain itself. First, symptoms are observed in patients, and after their death local injuries of the spinal cord due to splinters of metal or bone, burst blood-vessels, or tumours, are found. When the same symptoms are observed in another patient they can often be relieved by the surgeon owing to the knowledge so gained. To refuse leave to examine the body in such a case is to condemn someone else to die with those symptoms. Again, after destruction or division of some parts of the nervous system one can observe with the microscope the death and degeneration of groups of nerve fibres. Now we know that when a fibre is divided, only that part dies which is separated from the cell body and nucleus of the neuron to which it belongs. So we can discover in which direction the cell bodies of any bundle of fibres lie. But in the central nervous system the long fibres always conduct nervous impulses away from the nucleus, so we discover the direction in which nervous impulses run in the fibres we have cut. Finally, we can try the effect on an animal of cutting or stimulating some part of its nervous system. (The lower parts of the system will still work after the animal has been made unconscious by an anæsthetic or by removing its cerebrum.) By such methods we can distinguish five main pairs of ascending fibre tracts in the human spinal cord, besides numerous smaller groups. Two of these go to the cerebellum, and their injury does not affect consciousness, but causes unsatisfactory movements and postures, the brain being without information as to what the muscles are doing. Two of them send impulses only to parts of the brain concerned in consciousness. One serves both purposes.

Before we study the functions of the brain it will be convenient to deal with the special sense organs in the head which communicate with it directly and not through the cord. The organs of the chemical senses, taste and smell, are found in the mouth and nose. They work together, and much of the sensation we commonly regard as taste includes an element of smell. With the eyes and nose tightly shut, taste will not distinguish an onion from an apple. The taste organs mostly lie in the papillæ which roughen the upper surface of the tongue. There are four elementary kinds of taste, namely: salt, sweet, sour and bitter. Other tastes are combinations of these. Each elementary taste has different end organs. Thus, we taste sweet things

best with the tip of the tongue, bitter with the back.

The end organs of smell are a little patch of about one quarter of a square inch of yellow epithelium at the top of the internal cavity of the nose. The corresponding area in a dog is ten or more square inches, in a large shark 24 square feet. In man, smell is an unimportant, almost vestigial sense, but in the dog and many other animals it is the most important of all. So the dog's world is mainly a world of smells. But even in man it is the most delicate of the senses. We can smell mercaptan* at a dilution of 1 milligram in 20,000,000 litres of air. As about 1 cubic centimetre at a time is in the olfactory part of the nose, this means that we are affected by one twenty-thousand-millionth of a milligram, whereas the smallest object we can see with the naked eye is about a million times as large. In ordinary breathing most of the air goes past the olfactory cavity. In sniffing, some is sucked into it. No satisfactory classification of smells has yet been made.

* A product of decaying flesh.

CHAPTER SIX

THE NERVOUS SYSTEM *(contd.)*

THE EXTERNAL EAR, which is only found in mammals, is of little use to man, though some beasts can turn it so as to collect sound. In the internal ear, which lies in the thickness of the skull wall, are the organs of hearing and balancing. The ear-drum (Fig. 31) lies across a passage leading from the outside to the throat, and corresponding to the first gill-slit of a fish. The inner two-thirds of this passage are called the Eustachian tube, and serve to equalize the pressure on the two sides of the drum. If it is blocked by a cold the pressure becomes unequal, the drum is too much stretched to vibrate properly, and deafness results. The internal ear lies in a long "labyrinth." The organ of hearing consists of a tube called the cochlea, coiled like a snail's shell; that of balance consists of three "semicircular canals" and two smaller cavities, all communicating and filled with fluid. They are surrounded by further fluid which separates them from the skull (Fig. 6).

The drum is set in motion, like the diaphragm of a telephone receiver, by sound waves in the air. It transmits this motion through a chain of three small bones to a membrane covering a tiny oval window in the bony labyrinth. The bones serve to concentrate the energy from the drum on to the window, which is one-thirtieth of its area. This is necessary if air movements are to be transmitted to a watery fluid, which, being denser, is harder to move. When the oval window is pushed in another membranous window (Fig. 31) bulges out, and it is clear that the sound waves in the fluid must travel between them. The only path lies through the hearing organ in the cochlea. This includes a series of about 10,000 fibres (not nervous) of varying length and probably of varying tension, stretched across the tube of the cochlea, and joined by a fine membrane. Several fibres from the auditory nerve end in receptor organs on each of them. It seems that each will vibrate to one note only, like a wire in a piano. If we play a chord loudly near a piano, the wires corresponding to the notes start vibrating. Similarly in the cochlea each fibre responds to one note and excites the corresponding fibres in the nerve. Very pure musical notes only excite few fibres, but generally they are accompanied by over-

tones which give them their timbre, and excite the cochlea in several places. In ordinary noises and the vowels of speech the mixture of tones is still more complicated. Thus every sound is translated into a series of impulses travelling to the brain along a certain number of

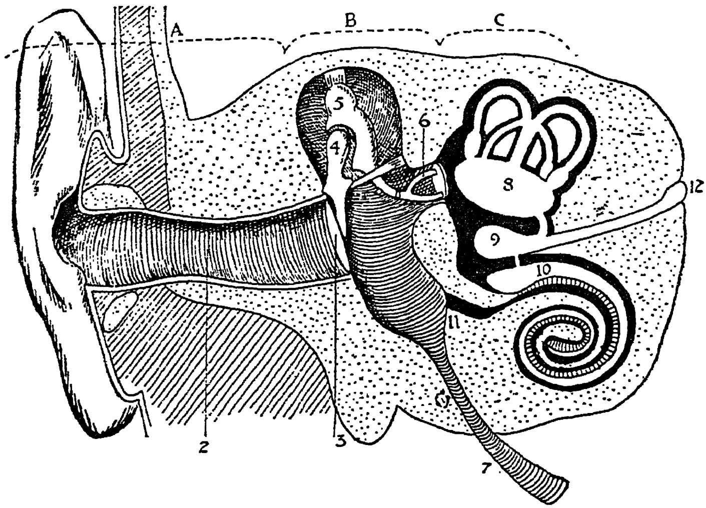


FIG. 31. Diagram of the human ear. A, outer ear; B, middle ear; C, inner ear. 1, the ear trumpet (pinna). 2, external ear passage (meatus) running to 3, the ear-drum (tympanum). On the inner side of this is the middle ear, containing air, and communicating with the cavity of the mouth by the Eustachian tube, 7. It contains the three auditory ossicles, 4, 5 and 6, which transmit the vibrations of the drum to the membranous window, to the right of 6, in the wall of the inner ear. The inner ear is entirely embedded in bone. It contains a fluid, the perilymph; this surrounds the "membranous labyrinth," 8, 9, 10, a series of membranous organs containing another fluid, the endolymph. 8, the utricle with the three semicircular canals arising from it; the organ of balance. 9, the sacculus, leading to 10, the spiral cochlea, the organ of hearing. Above 11 is a second membranous window which is pushed outwards when the first window is pushed inwards, and vice versa.

fibres of the auditory nerve, and we judge of the quality and intensity of the sound according to which fibres are excited, and how frequently. Its direction is judged mainly by the different intensities with which the two ears are excited.

The balancing organ consists of two parts. Two of its cavities contain tiny lumps of calcium carbonate called otoliths,* which are supported by "hair-cells" in which nerve fibres end. According to the fibres excited at any moment by the otolith pressing on the corresponding hair-cells we judge what objects are vertical, though here we are helped by our other senses. If we lean our head the otoliths roll on to a new set of hair-cells, a new group of fibres is excited, and we alter our opinion as to what line in our head is vertical. The reflexes excited by these organs are more important than the sensations. If an acceleration of our body, as on a swing or merry-go-round, moves the otoliths from the bottom of their cavities, we get a false idea of what is vertical, but we perform the right reflexes, and lean so as not to fall. The otoliths in fact behave like plumb lines in our heads. Even such simple animals as jelly-fish have otolith organs to enable them to swim the right way up, and they are generally found in animals which have to balance. Some shrimps put particles of sand into these organs with their claws when they moult. If given iron filings they put these in instead. When a magnet is now held over them, the filings press upwards, not downwards, and the shrimps swim upside down!

On each side one semicircular canal is horizontal, and the other two are in vertical planes at right angles. If we spin round, the fluid in one or more of them is left behind (like the water in a glass which we spin suddenly) and therefore moves relatively to the head. In doing so it presses on microscopic "hairs" projecting from cells, and excites nerve fibres running to the brain. After we have spun for some time the fluid moves with the head (as does the water in the glass), and goes on moving after the head has ceased to spin, giving the illusion that we are spinning the other way. In ordinary giddiness in a horizontal plane there are rapid reflex movements of the eyes which can easily be seen in others, and make things appear to spin round us. These reflexes are of great value in ordinary life as they keep the direction of our gaze fixed when we turn our heads quickly. We can become giddy in a vertical plane by turning round with the forehead or ear resting on a stick, and then raising the head. The violent reflexes of the limb and trunk muscles, which normally keep us from falling, now make us

* Statoliths, or concretions concerned with balance, would be more correct; but the term otoliths is still generally used in human physiology.

fall. In fish the hearing and balancing organs are a specialized part of a system of canals under the skin and opening by occasional pores, which enable the fish to appreciate movements of the water round it, and its own movements relative to the water.

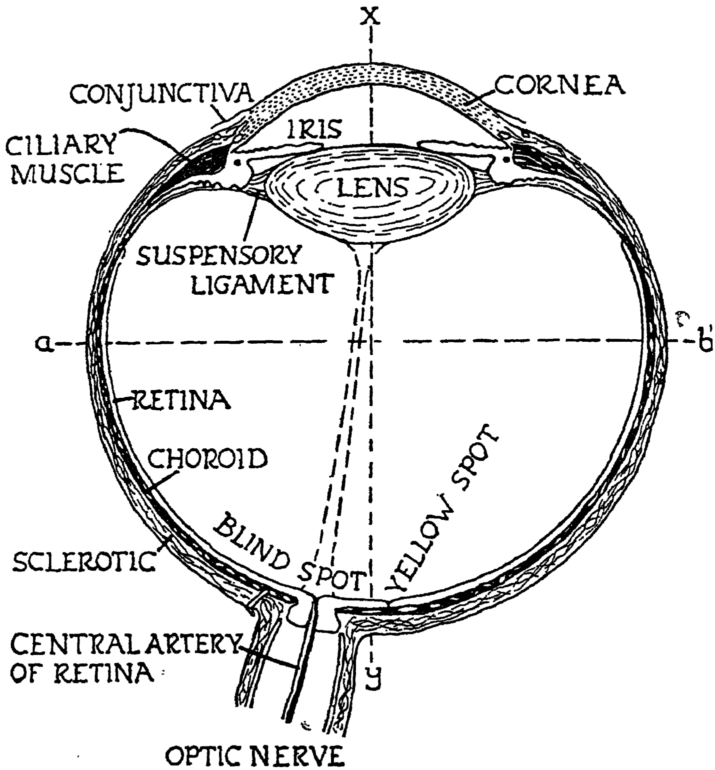


FIG. 32. Diagram of a horizontal section through the right eye of a man. The lens and iris separate the anterior chamber (filled with aqueous humour) from the posterior chamber (filled with the jelly-like vitreous humour). The shape of the lens can be altered by the ciliary muscle pulling on the suspensory ligament.

The eye is enclosed in a tough capsule, transparent in front only, and pierced behind by openings for nerves and blood-vessels. It can be turned by six muscles which run between its capsule and the skull. A section from front to back (Fig. 32) passes through the following

structures: (1) the window or cornea; (2) a chamber containing a watery fluid; (3) the iris, a ring of muscle, with pigment to keep out light, which regulates the amount of light reaching the back of the eye; (4) the lens, a horny body whose shape can be slightly altered; (5) a chamber filling most of the eye and containing a transparent jelly; (6) a fine membrane, the retina, which consists of several layers of nerve cells, and is sensitive to light; (7) a layer of cells containing dark pigment, which acts like the black lining of a camera, and prevents light which has once entered the retina from being reflected; (8) the tough white coat which envelops most of the eye, and helps, with the aid of the internal fluid pressure, to keep it to a definite shape.

The general structure is like that of a camera with its lens, diaphragm, and sensitive film; and the cornea and lens have such refractive indexes and curvatures that the images of external objects can be accurately focused on the retina. The image is upside down and right side left. If we shut the right eye, and press the outside of the left eyeball through the eyelid, we see a dark spot with a bright border well out to the right or against the nose, which appears to move up as we move the pressing point downwards. We are stimulating the part of the retina used for looking out to the right.

The focus of the eye is altered in birds and cold-blooded vertebrates by moving the lens bodily backwards and forwards as in a camera. In man and other mammals, however, the lens is fixed, but its shape can be altered. When we wish to look at an object near to us a circular muscle round the lens contracts, and it becomes more nearly spherical. The rays of light are therefore more bent in passing through it, and brought to a focus on the retina. If this muscle is not contracted they come to a focus behind the retina, and we see indistinctly. When we look at distant objects the directions of gaze of the two eyes are parallel, but when we look at a near one they have to be converged by the muscles which move the eyeball from outside, or we see double. The impulses coming to the brain from the eye muscles help us to judge distance accurately. This is why it is very hard to hit a near object accurately from the side with one eye shut, as any one can easily prove for himself.

If the focusing of the eye goes wrong it can often be corrected by spectacles. When the eye is too long the rays from distant objects con-

verge in front of the retina, and we are near-sighted. This is corrected by using concave lenses. If the eye is too short the rays from near objects converge behind the retina, and long sight results, necessitating the use of convex lenses for reading and fine work. If the cornea is more curved in one direction than another, like the bowl of a spoon, we cannot focus two perpendicular intersecting lines at the same time. This condition, which is called astigmatism, can be remedied by using lenses one side of which is a segment of a cylinder.

The iris contracts if strong light is flashed on to the eye, and expands in the dark, thus shielding the retina from too sudden changes. The microscopic receptor organs in the retina are called the rods and cones, from their shape. The rods are used for seeing in the dark, and do not distinguish between colours; the cones for vision in daylight. The diameter of a cone is about 2·5 μ, or 1/400 of a millimetre, so that there are over fifty million in each retina. We cannot distinguish two objects if their images fall on the same cone, as happens if the angle subtended by them at the eye is much less than a minute (the angle subtended by a halfpenny at 100 yards), however good our focusing may be. There is one spot on each retina, called the yellow spot, on which we focus the object at which we are looking. Vision is most accurate here in light (but not in darkness), and becomes dimmer as we pass away from it, until with the edge of our retina we cannot tell the form or colour of things, though we can see if they are moving. On one side of the yellow spot the nerves and the blood-vessels enter the eyeball and there are no rods or cones, so vision is absent here, since the optic nerve is no more sensitive to light than any other nerve. The existence of this blind spot can be demonstrated by putting two small objects such as halfpence on the table at a distance of about six inches and equidistant from the body. On shutting the left eye and looking fixedly at the left-hand object, meanwhile gradually approaching the head from a distance of a yard or so, the right-hand one will disappear when about two feet away. This fact interested Charles the Second, who used to amuse himself with it until he grew so expert that he could "take off" the heads of his courtiers.

The retina contains two layers of nerve-cells besides the rods and cones, and many fibres, the last relay of which runs into the brain as the optic nerve. Compared with the ear, the eye is much better at

judging the direction of the waves which stimulate it, but is sensitive to a much smaller range of wave-lengths. The longest wave-length that we can see in the red is about 0·0008 millimetres (0·8 μ), the shortest in the violet about 0·0004, so we can only perceive a single octave of the possible vibrations, the shorter invisible ones being ultra-violet and X-rays, the longer heat and "wireless." On the other hand we can perceive sound waves from 20 metres down to about a centimetre in length, a range of eleven octaves, seven of which are used in music. Moreover, the ear is better than the eye at analysing mixed vibrations. It is easy to analyse a chord into two or three notes, but we cannot tell without a spectroscope whether a given yellow is pure or due to a mixture of red and green light.

Many animals have eyes working on quite a different principle from ours, namely, built of little units each looking out in one direction (Plate 20 (ii)), just as each of our "cones" receives light from one direction only. Hearing organs are found in a few insects, often in their legs or bellies, and are provided with drums and hair-cells similar to our own.

We must now consider the brain (Fig. 33). The human brain is built on the same plan as the frog's (Fig. 7), but one part of it (the cerebrum) has grown in man and related animals to be much larger than the rest. It is on this part that the main differences between the behaviour of a man and a frog depend. We shall first consider the lower parts of the brain, which are not so very different in the two species. As the spinal cord enters the head it expands into the medulla oblongata, in which there are nerve-centres governing the involuntary activities of the body. For example, if an animal's head is cut off and the blood-vessels of the neck tied to prevent the loss of blood, it will not breathe, nor if we obstruct its aorta will the heart slow down. But if only that part of the brain above the medulla oblongata is destroyed, both these processes continue, though the breathing is clumsy. The medulla also regulates such functions as digestive secretion, including salivation; movements of the digestive organs, such as peristalsis and vomiting; and a number of reflexes in the circulatory system to be described later.

The involuntary muscles and glands concerned are controlled through the autonomic or involuntary nervous system. This consists

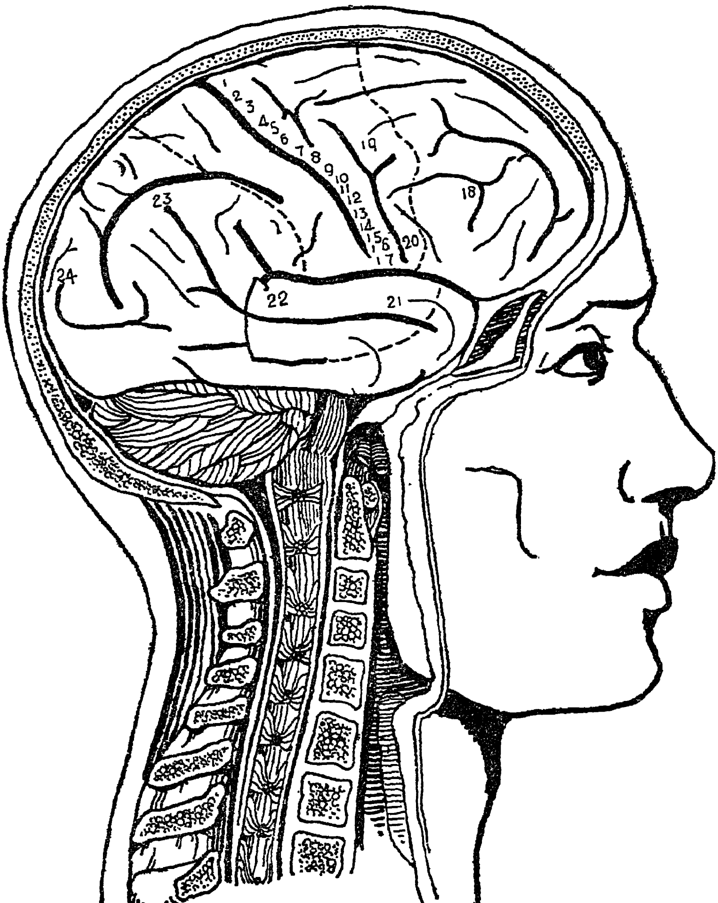


FIG. 33. Diagram of the human brain *in situ*. The cerebrum is in white, with the fissures as black lines. Behind and below it (coarsely shaded) is the cerebellum; in front of this is part of the medulla oblongata. The cerebrum conceals all the other parts of the brain. The medulla is continued downward as the spinal cord. Motor areas: 1, toes; 2, foot; 3, calf; 4, thigh; 5, belly; 6, chest; 7, back; 8, shoulder; 9, upper arm; 10, fore-arm; 11, wrist; 12, fingers; 13, neck; 14, eyelids; 15, cheeks; 16, jaws; 17, lips; 19, eyes; 20, tongue. Sensory areas: On and in front of the above motor areas; also 21, hearing; 24, vision; 18, areas concerned in co-ordination of speech muscles in left-handed person; 22, 23, areas concerned in speech and thought, particularly in left-handed person (*see* p. 221). (After Huxley and Herrick.)

of two parts: sympathetic (Chapter One) and parasympathetic. The latter system is composed of the vagus nerve which runs down the neck from the medulla, and supplies the chief involuntary organs from the thyroid gland down to the beginning of the large intestine; a few small nerves to glands and involuntary muscles in the head; and some nerves leaving the lower end of the spinal cord for such organs as the large intestine and urinary bladder.

There are two fundamental differences between involuntary and voluntary motor-nerves. The latter run straight to their destination, the former end in a ganglion where each excites one or more nerve-cells from which fibres run on to the muscle or gland. Also a single nervous impulse down an involuntary nerve has no effect. Several are needed to excite the rather sluggish organs which they supply. Most viscera get fibres both from the sympathetic chain and the parasympathetic system, and the two systems are generally antagonistic. Thus stimulation of the vagus slows down the heart, while the sympathetic speeds it up. The vagus makes the stomach and gut move and secrete their juices, while their sphincters such as the pylorus relax; the sympathetic diminishes their movement, secretion and blood supply, and tightens their sphincters. In other words the one promotes, the other hinders digestive activities. During violent exercise impulses pass down from the brain to the heart and gut; these set the heart beating faster and stronger, drive blood out of the vessels of the gut, and slow down the gut's movements. The autonomic nerve trunks also contain afferent fibres, but not very many, as the brain does not need very detailed information about events in the viscera.

Most of the nerve-fibre groups in the cord pass through the medulla, though some of the ascending ones end round neurones there whose axons pass on to higher parts of the brain; so that the medulla acts as a relaying station for the impulses which they carry. In the medulla, too, most of the fibre tracts to and from the higher part of the brain cross to the opposite side of the body. Hence the left side of the brain is concerned with nervous impulses to and from the right side of the body. The paths to and from the cerebellum, however, are mainly uncrossed.

Above the medulla lies the mid-brain. This contains the nerve-cells whose axons form the motor-nerves to the eye muscles, but its most

important functions seem to be in connexion with posture. If in an animal all the brain above the mid-brain is destroyed, it goes into a rigid state with the legs thrust out and the trunk stiff as in standing. Just as the spinal cord alone or along with the medulla will organize reflex muscular movements, so with the mid-brain in addition reflex posture is possible. Thus a "decerebrate" animal, i.e., one in which the cerebral hemispheres have been removed, though unconscious, can to some extent adjust its standing posture. If its head is bent down, it bends its forelegs, and so on. Similarly, if in a man the nervous pathways from the cerebrum are destroyed, certain groups of muscles cannot be moved voluntarily, but remain contracted in a state called spastic paralysis so long as the brain-stem is acting on them, whereas, if the injury to the nerve paths is lower down, the same muscles are equally paralysed, but flabby.

Behind this part of the brain is the cerebellum, an organ with several layers of nerve-cells on its outside, and a few large groups of cells inside, all connected up by numerous nerve-fibres which run between them and to other parts of the brain. When it is damaged there is no loss of sensation or power of thinking, but there is a loss of muscular tone, and a great deal of jerkiness and inco-ordination of movement. It bears the same relation to the proprioceptive system as the cerebrum to the exteroceptive. All the impulses from muscles, tendons, joints and labyrinth are co-ordinated there so that in a movement or posture the right muscles may be contracted to the right extent at the right moment. The rest of the brain without it is like a general who gets inadequate reports of the movements of his own troops. If a man with cerebellar disease tries to grasp an object, he moves his hand in a series of jerks and grasps in the wrong place.

Above these organs is the cerebrum, which, in man, but not in other animals, is many times larger than the rest of the brain. The human cerebrum contains more than a thousand million nerve-cells each connected by fibres with scores or hundreds of others (Fig. 34), so we can get some idea of its complexity by imagining a telephone exchange in which the whole human race were acting as operators. The main mass of nerve-cells lies on the outside, and this "grey matter" is folded to increase its area. In the middle, at the top of the brain-stem, are two masses of nerve-cells called the optic thalami, into which run the optic

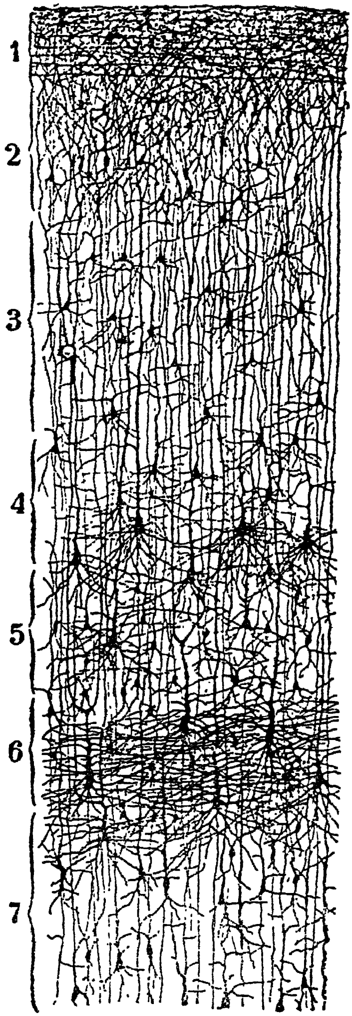


FIG. 34. Microscopical section of part of the human cerebral cortex (from an infant), to show the nerve-cells and their interconnecting processes (in black). 1–7, cell layers with different characters.

nerves and also fibres from below which carry up impulses from all the other sensory nerves on the opposite side of the body. A child born without cerebral cortex but with thalamus lived for three years without showing as much signs of consciousness as a normal baby a few days old. On the other hand a dog without cerebral cortex can walk about, though it runs into obstacles; but it shows no signs of recognizing anything, and food has to be placed in its mouth before it will eat. Judging from cases of disease in man, a dim kind of consciousness seems to be associated with the thalamus. When all the paths leading upward from it on one side are destroyed, the sensations on the opposite side of the body are abnormal. Light touch is not felt, but a slight scratch is felt as a horrible pain which cannot be localized, and the touch of a warm bottle as a huge pleasure. The more complicated senses, such as vision, are not represented in the thalamus, though it acts as a relay for visual impulses.

Different parts of the cerebral cortex have very different functions, and about half of it has been properly mapped out as regards its function (Fig. 33). Gentle stimulation of certain areas gives rise to movement, generally of muscles on the opposite side. This is always fairly well co-ordinated, i.e., a number of muscles work together, as is the case in voluntary action. The size of the area devoted to a group of muscles depends on the complexity and delicacy of the movements required of them. Thus the tongue has a cerebral area as large as the whole trunk, and the eye muscles an area about a third as large as all the other muscles put together. When a motor area is irritated, as by a splinter of bone or a small tumour, a special type of epileptic fit results, in which the involuntary muscular movements begin in the muscles governed by the irritated area. A knowledge of cerebral localization renders a surgical cure of fits of this kind possible. When part of the motor area is destroyed the corresponding muscles are paralysed, though later on other areas may partially take its place, and some voluntary control return. In front of some parts of the main motor area, especially on the left side, is a region whose injury in man causes, not paralysis, but a failure of the more complex movements, such as those involved in speaking and skilled manual operations. Finally, we must remember that when we are "doing nothing" the cortex is all the time inhibiting the postural centres in the brain-stem

from producing rigidity, so that a voluntary movement may sometimes merely be a stopping of this inhibition.

The main motor area and the region just behind it constitute the sensory area for all the senses except the special senses of sight, hearing, taste and smell. It is gradually being mapped out, and war injuries gave us a great deal of information. The sensory area for each part of the body includes the corresponding motor area and an area behind it. The hands have a very large proportion of the whole.

If the brain is injured a little behind the sensory area, the sensations are still felt but cannot be put together. For example, a man can state just what part of his hand is being touched, and whether any finger is bent or not, but he cannot say what sort of object he is holding in his hand. This part of the brain is therefore concerned in putting sensations together and interpreting them.

The optic nerves join before reaching the brain, and half of each crosses over, so the left side of the brain gets fibres from the left side of each retina, both of which look out on the right. So if the left visual area is destroyed a man can see nothing to his right with either eye. Similarly the different parts of the field of vision are represented on the visual area. If the visual areas of the brain are destroyed a man is quite blind, but may retain a good deal of visual memory; but if the neighbouring areas are destroyed, this too is lost.

In thought and speech a great many parts of the brain are employed at once. Thus to understand fully the meaning of the word *apple* we require memories of sight, hearing, smell, taste and touch, and the power of co-ordinating them. Some parts of the cortex are supplied entirely with fibres from other parts and clearly serve as centres for association and co-ordination. We are gradually finding out the functions of these parts by studying the effects of wounds and the degenerative changes found in the brains of the insane. In right-handed people the left cerebral hemisphere generally contains the main speech centres (and vice versa); injury of a large area of this will cause failures in speech, and in the thought behind it. According to the part injured there may be a mere slurring of words with apparently fairly clear thought, an inability to remember the names of things, or a failure to construct sentences and to think out problems. But the co-ordination of the brain cells is less understood than that of other organs, to which

question we shall turn in the next chapter. We can only emphasize the very important part played by inhibition, that is to say, the checking by one part of the brain of the activities of another part. In the spinal cord one reflex can inhibit another. For example, in a decapitated animal a stimulus, which would be painful to an animal with a head, at once inhibits reflex scratching movements. Voluntary attention means an inhibition of all our mental activities but one, and resistance to temptation is an inhibition of our more primitive activities, such as eating or losing our temper.

Many pathways are known for nervous impulses from the brain down the cord to the motor-cells in its grey matter whose axons form motor-nerves. One leads from the motor areas of the cerebral cortex to the opposite side of the cord, and is concerned in voluntary movements. Others descend from the mid-brain, which is under the influence of the cerebellum, to the opposite side of the cord, and are mainly concerned with posture and muscular tone. Another leads from the medulla, and is concerned with rapid reflexes to stimulation of the labyrinth, i.e., to keeping one's balance.

CHAPTER SEVEN

ORGANIC REGULATION

THE NERVOUS SYSTEM serves to co-ordinate the activities of the different organs to some extent, but it is not in itself essential for the life of the tissues. A leg will live for years without nerves, but only for an hour or less without blood or some artificial substitute for blood. The cells in a higher animal are like skilled workmen, very efficient at their own job, but not at other jobs. Thus a single cell in hydra may serve for protection, be sensitive to external stimuli, contract when stimulated, pass on excitation to its neighbours, and perhaps secrete mucus, but in none of these ways will it act as efficiently as the various cells of a mammal, each of which performs one of these special functions.

The latter are enabled to specialize largely because they have a nearly constant environment, constant in chemical composition and temperature, and do not spend any energy in adapting themselves to change in it. This environment is supplied by the fluid part of the blood. In this and the next chapter we shall consider some of the factors in the internal environment, and how they are kept steady or adapted to new conditions. Most of the general symptoms of disease are due to upsets of the internal environment.

Each organ must have food, oxygen, and a means of getting rid of waste products. But this is not all. It must have them in the right amounts. Too much oxygen is just as deadly as too little. And it must also have in the right amounts other substances which it does not use for work or repair. An animal dies if we halve or double the amount of potassium salts in its plasma, though it does not turn potassium salts into anything else. So these too have to be kept steady. Further, an organ may need different amounts of a given substance at different times. If a muscle suddenly starts work, its O_2-consumption and CO_2-production increase about fifty times. It was already using most of the oxygen in the blood which passed through it, so it must increase its blood supply correspondingly. When it is at rest about five out of every six of its capillaries are shut. When it begins to contract these at once open and the others open wider. The small arteries also open

wider. In a resting muscle they are kept almost shut by the slight alkalinity of the blood, and also probably by the presence of oxygen. Now if we cut the leg off a recently killed frog and run fluid through the blood-vessels, they will open up if this fluid is not sufficiently alkaline, or is short of oxygen. Just the same thing happens when a muscle contracts or a gland begins to secrete. The O_2 flows from the blood and CO_2 is poured into it, making it acid; the blood-vessels relax and widen, and the organ obtains an adequate flow of blood. Other products of activity besides CO_2 probably co-operate in producing this effect.

But when any large organ opens up its vessels the arterial pressure would fall unless the heart pumped harder. The other organs would then go short of blood. We must therefore study the working of the heart. Like other involuntary muscles, it will work without any nervous control. If we take the heart out of a recently dead animal or man, and supply it with warm blood or an appropriate salt solution containing oxygen, it begins to beat again and may go on for many hours. Even an isolated piece of it will beat. In a mammal the beat starts at the entrance of the great veins to the right auricle in a special piece of tissue known as the "pacemaker," which does not contract but stimulates the neighbouring muscle. If we warm the pacemaker, the whole heart beats faster; if we destroy it, the heart first stops, then begins to beat at a slower pace of its own. The auricles contract almost instantaneously when stimulated by the pacemaker, but they are only connected with the ventricles by a narrow bridge of conducting tissue in which the wave of excitation is delayed for about one-tenth of a second, and then passed on almost simultaneously to all parts of the ventricles. If the bridge is damaged, as in some forms of heart disease, the ventricle may only respond to every second or third beat of the auricles. If it is destroyed they beat at their own rather slow rate, and cannot be speeded up.

Now if we take an isolated heart, or a heart whose nerves have been cut, and give it an increased supply of blood, it can increase its output per beat but will not increase its rate at all.

The rate is governed by two pairs of nerves. Of these, the vagi are one; if they are stimulated the heart slows down; if they are cut it speeds up, showing that they are normally acting as a brake on it,

mainly through the pacemaker. The other pair, called the accelerators, come through sympathetic ganglia from the spinal cord. Stimulation of them speeds up the heart. Both pairs are governed by the same centres in the medulla oblongata.

If the blood supply to the heart is increased, the great veins and auricles are distended, and receptor organs in their walls send impulses up to the brain which result in the vagus brake being slackened by a reflex action; and if the stimulus is sufficient, the accelerators are set to work. Hence, when more blood reaches the heart from the open vessels of an active muscle, it increases its rate and force.

Another set of reflexes keep the arterial pressure steady. A pair of nerves called the depressors run from receptor organs in the aorta to the medulla oblongata, which they enter with the vagus. If the aorta be distended by an abnormally high blood pressure, impulses run up them to the medulla. The reflex response to this is a slowing of the heart by the vagus and an opening of small arteries. The opposite occurs if the aortic pressure falls. There is also a pressure gauge in the brain itself. If pressure is put on the brain from outside, for example, by a clot of blood under the skull, its vessels will collapse, and the brain will force the heart to raise the arterial pressure till they open up again. In this way the arterial blood pressure is kept steady, so that any organ can obtain the blood supply it needs by opening up its blood-vessels.

But the brain does not allow an indiscriminate competition between different organs for blood supply. The arteries as well as the heart are under nervous control. A series of nerves called vasoconstrictors run in the sympathetic system to the smooth muscle of the arterial walls. The vasoconstrictors come into play in circumstances which affect the body as a whole, such as change of posture, or violent exercise. When a man gets up after lying down the blood tends to flow into his belly and legs, and this is prevented by the contraction of the arteries of these parts, under impulses from the vasomotor centre, which lies near the heart-regulating centre in the brain. If he has been in bed some days the vasomotor centre is out of practice and his brain runs short of blood, so that he becomes dizzy and may faint.

If there is a great deal of blood in the guts and skin, as when we are sitting before the fire after a heavy meal, this may even happen on

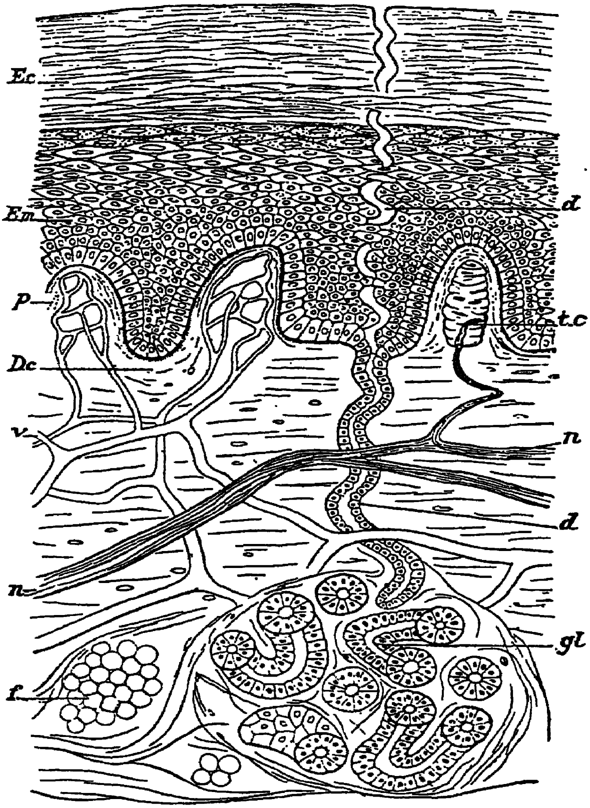


FIG. 35. Diagram of a microscopical section through the human skin. The ectodermal part or epidermis consists of undifferentiated, actively dividing cells below (*Em*), which gradually become changed into horny plates (*Ec*). It also gives rise to tubular invaginations, the sweat glands, one of which is seen at *gl*, with its duct (*d*). The mesodermal part or dermis consists of connective tissue (*Dc*) with blood-vessels (*v*) and nerves (*n*), some of the latter leading from touch organs (*tc*). It also contains fat cells (*f*). No hairs or sebaceous glands are shown in the section. (Huxley, *Lessons in Elementary Physiology*, 1915.)

getting out of a chair. Again, during muscular exertion the arteries to the guts contract, and digestion has to stop.

The vasoconstrictor nerves are also excited by chemical stimuli to the brain. If we are throttled or breathe very impure air, the CO_2 of the blood goes up and the O_2 down. The vasomotor centre then narrows down all arteries except those to the heart, lungs, and brain, and the blood pressure rises. These three essential organs must have an adequate supply of oxygen, whatever else goes short. The other organs, if left to themselves, would open up their vessels, but in a general emergency they are not allowed to do so. The heart is also speeded up.

There are also vasodilator nerves. For example, when a dog gets hot the vessels in its tongue are opened up by a special nerve. Moreover, many of the nerve-fibres whose stimulation causes pain send branches to the local blood-vessels. When a pain spot is stimulated, impulses run up to the spinal cord. They also run directly to the local vessels, which open up, causing reddening of the skin; this is almost the only reflex in higher animals of which the nervous path is entirely outside the central nervous system.

The above are cases where an organ gets blood which is not to be used mainly as a gas carrier. The same occurs in an actively secreting gland. A salivary gland when active uses three times as much oxygen as when at rest. But it also needs a great deal of water to make saliva, and it is as a source of water rather than of oxygen that it needs blood. Its blood supply must go up five times, and as the ordinary chemical call for blood is not effective, a vasodilator nerve is used. As the blood supply goes up more than the oxygen consumption, the venous blood of the active gland is actually redder than usual.

A much more important case of non-respiratory blood supply is the skin's (Fig. 35). The human skin excretes energy just as the kidneys excrete matter. All the heat produced in the body has to get out, and seldom does more than a fifth of it get out in the breath. The remainder goes through the skin, and its loss is regulated in such a way as to keep the temperature of the body very constant. If we go into a hot room the same amount of heat has to be lost in a given time, but it is obviously harder to get rid of it. If we work hard and produce more heat in our bodies, more heat has to be lost in a given time, though the loss of a given amount is no harder. In each case the skin responds in the

same way. Its small arteries open up and it gets red and warm. Heat is thus brought from the inside to the surface in large amounts and rapidly lost, as from the radiator of a motor vehicle. If this means of losing heat is insufficient, we begin to sweat. The sweat comes from microscopic glands under nervous control. It consists of water containing less salt than the plasma. When this evaporates the skin is greatly cooled, for water has a big latent heat of evaporation. Sweat that does not evaporate does not cool us, and it cannot evaporate if the air is already saturated with water vapour. So sweating is useless in a hot and damp atmosphere, which is therefore far more oppressive than a dry one of the same temperature. The ordinary thermometer does not tell us whether we shall be able to lose heat or not. For this purpose we use a "wet bulb" thermometer. The bulb is wrapped in a wet cloth, so that the drier the air is, the more heat it can lose by evaporation. It is therefore in the same position as a man whose clothes are soaked with sweat. If the air is saturated with water the wet and dry bulb thermometers have the same reading, if the air is dry the wet bulb thermometer may read more than 100° Fahrenheit lower.

Men can stand dry heat far above boiling point, staying in a room where a steak is cooked in five minutes, and only coming out when their hair begins to singe. But a wet bulb temperature above 90° Fahrenheit is fatal, and above one of 75° Fahrenheit the capacity for work is lowered. We get an idea of the efficiency of sweating by considering a man in fairly dry air at body temperature (98·5° Fahrenheit). He can lose no heat by conduction or convection, so it must all be used in evaporating water. He has to lose 3,000 kilocalories per day. But the evaporation of 1 litre of water at body temperature requires 570 kilocalories, so in a day he must sweat 5·3 litres, or 9·3 pints. Actually many men can sweat 1 litre per hour, and the world's sweating record is held by an English coalminer who lost 18 pounds (1·8 gallons, or 8 litres) in 5½ hours.

To make up for the loss of sweat one must drink more water and eat more sodium chloride than usual. Miners working in great heat are therefore fonder than the average man of bacon, kippers and salt. Many animals, such as dogs, have very few sweat glands, but produce a very thin saliva which they evaporate by rapid shallow breathing, panting with open mouth and tongue hanging out.

Several parts of the brain are concerned in heat regulation. They receive nervous impulses from the skin, and also from local organs in the brain which measure the temperature of the blood like thermometers. Thus, if certain parts of an animal's brain, or the blood going to them, are heated, the animal begins to flush and sweat, and the rest of its body is cooled down. If the brain is cooled the animal shivers and its temperature rises.

During adaptation to heat we cannot cut down our heat production except by keeping still, but when cold, besides shutting down the skin vessels, we first tighten up our muscles, then shiver, and finally take exercise. In all these ways more heat is produced. In many diseases the temperature rises. This is not due to increased heat production, but to diminished heat loss owing to perverted function of the temperature centres. A man whose temperature is thus rising feels very cold until it has reached the new level to which he is regulating. He shivers and complains of the draught, to which he may put down his illness. If his temperature falls quickly he sweats profusely and feels very hot.

Mammals and birds have a nearly constant temperature, but other animals have a variable temperature, a fraction of a degree above their surroundings. If we warm a "cold-blooded" animal through about 5° centigrade we double its rate of oxygen consumption, and all its other activities. For example, it is possible to read the temperature within 1° Fahrenheit by measuring the distance walked by an ant in a minute! Cold-blooded animals cannot move quickly in winter, and mostly die or rest in holes. The activities of mammals and birds are not slowed down, so they are the dominant animals in temperate and cold climates. But in hot countries, snakes, crocodiles, and so on, are able to compete successfully with warm-blooded animals. A few mammals, such as hedgehogs and dormice, compromise by sleeping through the winter at a low temperature (and therefore a low rate of oxidation), but they never let their temperature fall to that of their surroundings.

We must now turn to chemical regulation of the composition of the blood and tissues. It will be convenient to begin with the gases, the quantity of which in the blood is regulated by breathing.

The obvious duties of the lungs are to get rid of CO_2 and let in O_2, and if we go into a room containing say 6 per cent of CO_2 instead of

the normal 0·03 per cent, or 10 per cent of O_2 instead of the normal 20·9 per cent, the breathing increases greatly. However, a small drop in the O_2 of the air breathed has no visible effect on the breathing, because the hæmoglobin is already almost saturated with oxygen at a pressure less than that in the lungs. So want of O_2 cannot be what normally keeps the breathing going. To find out how the breathing is regulated we must take the samples of air from the very bottom of the lungs, where it is in equilibrium with the blood. This, which is called the alveolar air, can be obtained at the end of a deep breath out. The amount of carbon dioxide in it is very constant, about 5½ per cent, whereas the amount of oxygen varies a good deal. If the amount of carbon dioxide increases by only 3 per cent of its normal value, the breathing is doubled; if it falls by the same amount, as after voluntary over-breathing, the breathing stops. The main reason why we breathe more during moderate muscular exercise is because more carbon dioxide is being produced, and this stimulates the respiratory centres in the brain to make the breathing muscles do more work. Thus the lungs have the function of keeping the CO_2 pressure in the tissues at the normal level, not merely of excreting it.

Carbonic acid seems merely to act on the respiratory centre in virtue of its being an acid. If another acid, such as hydrochloric, is injected or drunk, the breathing is greatly increased, while it slows down when an alkaline substance such as sodium hydrogen carbonate is taken. The most familiar case, however, is that of very violent exercise. When the muscles are working so fast that they cannot get enough oxygen for their recovery process, lactic acid accumulates in them and leaks out into the blood, from which it is only gradually removed. So after running a quarter-mile the extra carbon dioxide is got rid of in the few minutes of violent panting which succeed the race, but a small increase of the breathing, due to lactic acid, may persist for half an hour or so. During this time the alveolar carbon dioxide pressure is kept below normal by the extra breathing, thus compensating for the acidity which would otherwise be produced by the lactic acid.

Serious oxygen-want also excites the respiratory centre. If one goes into air containing only about half the normal 20·9 per cent of O_2, one at once begins to pant, but after a while the panting dies down, because a lot of CO_2 has been blown out of the body by the increased

breathing, and the respiratory centres have no more reason to discharge nervous impulses than before, their normal stimulus, CO_2, being reduced in quantity. So a man who has gone into bad air at first pants enough to keep his blood supplied with oxygen. Then the breathing becomes normal, and he falls unconscious with oxygen-want. A candle is often a much better measure of oxygen-want than one's own feelings.

Another way in which the breathing is affected is by the process of digestive secretion. When the stomach secretes hydrochloric acid the blood would be too alkaline if carbonic acid were not kept back to take its place, so the breathing is slightly slowed down. Later on, the pancreas and intestine begin to remove alkali from the blood for their secretions, and to prevent it getting too acid the breathing has to be increased. These changes are too small to observe directly, but can easily be measured. We can get some idea of why the alkalinity of the tissues has to be regulated so carefully by experimenting with tissue or enzymes taken from them. If we take a dead organ and preserve it carefully from bacteria it does not putrefy. But if it is kept at body temperature the tissues gradually soften and are found to be digesting themselves. This is due to enzymes in them. The dying tissues produce acids, and in a slightly acid medium these enzymes work very much more rapidly than in an alkaline or neutral one.

Thus, to prevent an organ from digesting itself it must be kept slightly alkaline. The best known of these enzymes is that in the liver which breaks up its glycogen into sugar. A quite fresh liver, besides being very tough, does not taste sweet. If it is allowed to digest itself for a few days it not only becomes tender, but sweet. Some other enzymes act more rapidly in a medium more alkaline than the normal, so if the reaction of the tissues is altered the normal balance between the different chemical processes is upset, and death may occur.

Just as the lungs regulate the amount of gases in the blood, the kidneys regulate the amount of the soluble bodies. The blood which passes through these organs is always altered so as to resemble an "ideal" blood. Thus, if there is more water in the blood plasma than in this ideal or standard plasma the kidney secretes an unusually watery urine, and the plasma of the blood in the renal vein therefore contains less water than the arterial blood, and resembles the standard plasma

more closely. If, as is more usual, especially in hot weather, there is rather less water in the plasma than in the standard plasma, the kidney secretes a concentrated urine, so the blood leaving the kidney contains more water than that entering it. The substances found in blood and urine can be divided into two classes. The first class includes almost all foreign substances, for example, iodides, dyes, or foreign proteins injected into the blood. These are removed by the kidneys, however little there is in the blood. It also includes some very important waste products, such as urea, the substance which contains most of the nitrogen resulting from protein oxidation. The rate at which such substances are excreted is roughly proportional to the amount in a given volume of blood. The second class includes most of the normal constituents of plasma, such as sodium, potassium, calcium, magnesium, chloride, bicarbonate, phosphate and sugar. These substances are only excreted if the quantity of one of them contained in a given volume of plasma exceeds a certain limit, called the "threshold." For example, the amount of chloride in the plasma is generally a few per cent above the threshold, and there are, therefore, chlorides in normal urine. But if we drink a lot of water after violent sweating, the amount of chloride in the plasma falls below the threshold, and it disappears from the urine. Normal blood contains about 0·10 per cent of glucose, a simple sugar. If a healthy man takes 100 grams of glucose the amount in the blood rises to about 0·13 per cent, but none appears in the urine. The threshold value for the kidney is about 0·17 per cent. If, therefore, the arrangements for storing sugar are out of order, as in diabetes, a dose of 100 grams will make the blood sugar rise above 0·17 per cent, and sugar will appear in the urine.

Besides excreting substances found in the blood, the kidney makes a few substances. For example, sulphuric and phosphoric acids are made throughout the body by the oxidation of the proteins. The kidney has to get rid of these, but its cells and those of the urinary passages are damaged by strong acids. It therefore excretes the sulphuric acid not as such, but as ammonium sulphate, which is neutral in reaction. But there is not enough ammonia in the blood to furnish all that is required for this purpose. Ammonia and ammonium salts are poisons when injected into the blood stream, and the liver converts almost all the ammonia reaching it into urea, which is nearly

harmless. So the kidney has to make its own ammonia, and the more acids it has to excrete the more ammonia it makes.

The kidney is doing work like a muscle, for work has to be done in concentrating substances, just as in compressing gases. For example, to concentrate the urea in a litre of blood into about 20 cubic centimetres of urine, as the kidney does every twenty minutes or so, requires at least as much work as to compress a litre of gas containing as many molecules as there are urea molecules in the blood, into 20 cubic centimetres. Actually the number of urea molecules in a litre of blood is the same as that in a litre of gas at a tenth of an atmosphere pressure, so the work needed is that required to compress this gas to a pressure of five atmospheres, i.e., 40 kilogrammetres. In order to do this work the kidney needs oxygen. Its oxygen consumption can be measured by determining the rate at which blood flows through it and the amount of oxygen lost by this blood. As a matter of fact, the kidney uses a good deal more oxygen per gram per minute than the heart, and like the heart, will increase its oxygen consumption three or four times if it is given work to do.

But if we inject salt solution of about the composition of plasma, the kidney needs no more oxygen, although the volume of urine secreted per minute is increased. This is because it has no work to do in concentrating the salt, but it merely acts like a filter. If on the other hand we inject urea or sodium sulphate, its oxygen consumption increases, as these substances have to be concentrated. Other glands behave in a similar manner, requiring more oxygen when stimulated to do work.

CHAPTER EIGHT

THE INTERNAL ENVIRONMENT

WE SAW THAT, among other things, the kidney was responsible for preventing the amount of various inorganic substances in the plasma from rising above fixed values, while, as will be seen later, other organs serve to keep them up to those values. What would happen if the amounts of these bodies deviated from the normal? Their importance is shown by the extraordinary fact that an organ such as the heart or liver can be kept alive for many hours in a solution of inorganic salts which are present in nearly the same proportions as in plasma. For mammalian organs such a solution is:—

$NaCl$, 0·8 per cent; KCl, 0·02 per cent; $CaCl_2$, 0·02 per cent.; $MgCl_2$, 0·01 per cent; $NaHCO_3$, 0·1 per cent.

This solution, whose composition was worked out by Ringer, must be saturated with oxygen, and a little glucose may be added as a source of energy. Now if we leave out the various constituents, or increase them above the standard amounts, we shall find out what functions they are performing. The salts do not permeate the cells, or only do so very slowly, but affect their surface properties. If the solution perfusing, say, a rabbit's excised but still beating heart is diluted with water, the heart swells up and stops. It has become sodden with water as does the skin of the hands in a hot bath, for water runs into the cells and dilutes their contents. If we make the solution too strong the cells shrivel up from loss of water. If we replace most of the sodium chloride by the corresponding number of molecules of cane sugar the heart goes on beating. Clearly the main function of the sodium chloride is to prevent the cells from taking up too much water. If we leave out the potassium the heart goes into a state of cramp. Potassium is needed for its relaxation. If we leave out the calcium it stops in a flabby condition, and so on. A heart so stopped may be revived hours later by adding the missing salt. Other organs behave in the same way. Thus, if there is too much or too little calcium in the fluid in its blood-vessels, the kidney refuses to hold back sugar when the amount of sugar in the fluid perfusing it is below the normal threshold value.

We can also observe effects of the same kind on a man or animal,

though here the nervous system is generally affected before the other organs. Thus, if a man drinks water for some hours more rapidly than his kidneys can get rid of it he gets cramps, and later convulsions. If he lowers the calcium to half its normal value he gets another type of cramp, and so on.

One of the most remarkable things about the plasma salts is that they are nearly the same as those of sea-water diluted with water to about three times its volume. Such a solution would, however, among other things, contain too much magnesium and sulphate. Now the blood of marine invertebrates is very like sea-water, while that of sea-fish is generally somewhere between that of invertebrates and that of land vertebrates. Many people, therefore, think that land vertebrates are descended from fish which left the sea when it contained less salt than now, and that our blood plasma has kept the composition of the sea-water to which the cells of our ancestors were accustomed.

Besides the inorganic substances mentioned, the plasma contains phosphates, which are also kept in by the kidney. They play a very important part in the formation of bone, which consists largely of calcium phosphate. There is an exceptionally large amount of phosphate in the plasma of growing children, and of adults who have broken a bone and are engaged in repairing it. If the amount of phosphate or of calcium in a child's plasma falls below normal it is unable to form bone properly, and develops rickets.

Although an organ can be kept alive for many hours by inorganic substances, yet organic compounds are of course needed for its prolonged existence, and a heart will survive longer if, for example, a little sugar is added to its salt solution. As we saw, the blood contains about one part in a thousand of sugar, and this does not fall much in a starved man or animal. In this case glycogen is broken down by the liver to keep the sugar level up, and after the glycogen is mainly used up, the organs then oxidize fat rather than sugar, and leave the blood sugar about normal. In the same way the amount of amino-acids remains fairly steady, though of course there is a small temporary rise after a protein meal. The amount of fat varies somewhat more, and after a very heavy fat meal the plasma may be quite milky with microscopic fat drops.

The liver plays an important part in keeping the amounts of sugar

and amino-acids steady. It stores extra sugar as glycogen, and removes the ammonia from excessive amino-acids. The residue of the amino-acid molecule left can be oxidized, and in some cases can be made into sugar if required. But besides dealing with excess of normal blood constituents it can destroy poisonous substances coming to it from the gut. These substances are generally the result of bacterial action there. The bacteria attack the proteins of our food, but have not enough oxygen to utilize them fully. They therefore excrete unoxidized fragments of proteins, just as the yeast cell excretes ordinary alcohol made from sugar which it cannot burn. Among these excretory products are phenol ("carbolic acid"), cresol, indol and skatol. The last two are foul-smelling, and all are poisonous. They are absorbed from the gut, but on reaching the liver they are combined with sulphuric acid, apparently by an enzyme, to form quite harmless substances which are excreted by the kidney. If, however, they enter the blood in very large amounts a proportion gets past the liver and the whole body appears to suffer. The liver acts in the same way with many other substances. It has more varied chemical functions than any other organ.

Besides foodstuffs and various colloids with which we shall deal later, the plasma contains in exceedingly small amounts certain organic substances of great importance which are poured into it by special organs, including the ductless glands, such as the thyroid. Some of these substances, like adrenalin, are present in varying amounts and act as hormones or chemical messengers between different organs. Others seem to be present in fairly constant amounts, and are needed for the normal working of the body (*see also* pp. 260–1).

Insulin is produced by certain microscopical "islands" of tissue in the pancreas, and passes out of them into the blood stream. If these islands of insulin-producing tissue are removed or diseased the tissues become more or less completely unable either to oxidize or store the sugar of the blood. The amount present in the blood increases, especially after meals containing carbohydrates, and when it rises above the threshold value the kidney excretes it and it is wasted. What is even worse, the tissues begin to make sugar from proteins, and this too is excreted. So a man with severe disease of the parts of the pancreas which make insulin gradually wastes away. This condition is called diabetes. If he is still making some insulin we can often keep

him alive on a meagre diet which he can just deal with, but in severe cases we have every day, or several times a day, to inject insulin made from the pancreas of animals. Unfortunately an overdose of insulin will depress the blood sugar below normal, which may bring on convulsions and death. Insulin has not yet been obtained in a pure state, but we know that very little is needed, for less than one milligram per day of our strongest present preparation is needed even in severe diabetes.

The thyroid gland in the neck makes a substance called thyroxin, which has been obtained in a pure crystalline form and whose chemical structure is known. Absence or removal of the thyroid does not lead to immediate death, but to a condition called myxœdema in the adult mammal, cretinism in the young. In this state the resting O_2 consumption is only about 60 per cent of the normal, and the adult patient becomes fat, sluggish, stupid and bald; while a child develops abnormally and is idiotic; and a tadpole never metamorphoses into a frog. These conditions can be completely cured by administering thyroxin or extracts of the gland. Fortunately, thyroxin is not destroyed, like insulin, by digestive enzymes, so it can be given by the mouth (Plates 13 (i), 14).

Thyroxin has such a powerful effect that only about a third of a milligram per day is needed to keep a thyroidless man normal, and this amount will cause the oxidation of a quarter of a million times its weight of glucose. The thyroid gland sometimes swells up and produces too much thyroxin. The resting O_2 consumption then rises and may reach double the normal amount. In one hospital the patients in the ward reserved for hyperthyroidism eat twice as much as those in any other ward! They become thin and nervous, and their eyes tend to protrude. They can generally be cured by cutting out the gland wholly or in part.

Thyroxin is an organic substance including four iodine atoms in its molecule, so if there is not enough iodine in the food and drink it cannot be made in sufficient quantity. In many inland districts swelling of the thyroid is found along with a low or normal resting metabolism. This disappears when a few milligrams a week of an iodide are given. The gland which has been overworking in an attempt to make thyroxin with too little iodine rapidly recovers. The same simple

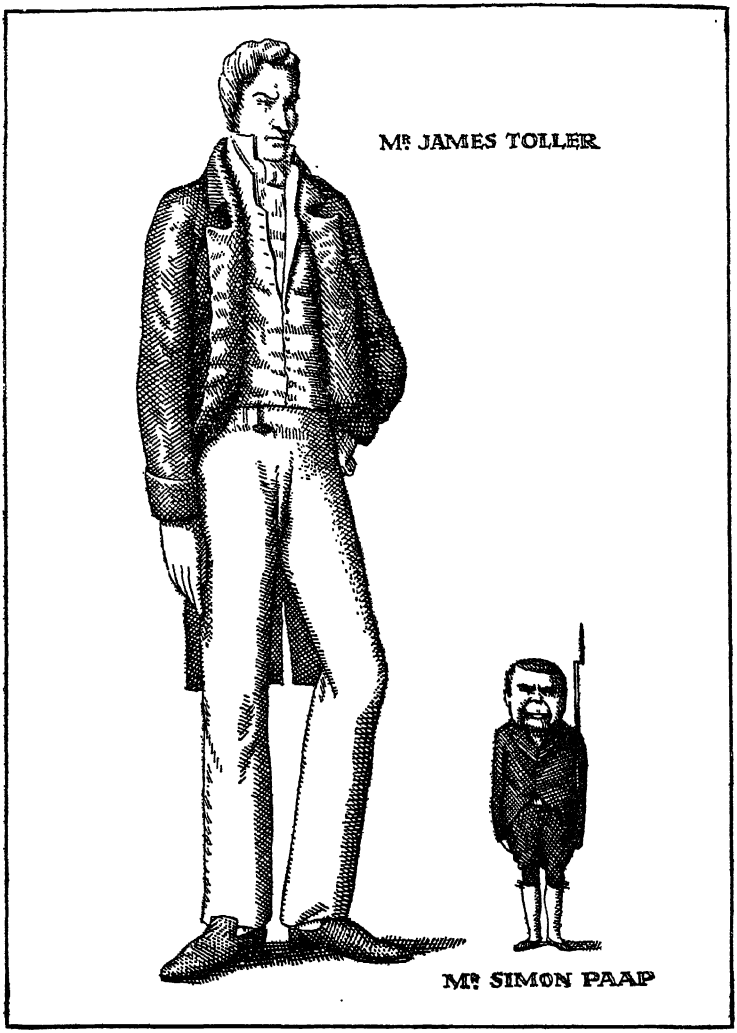


FIG. 36 (from an old print). A giant and a dwarf. The giant was only seventeen years old, but 8 feet high. His condition must have been due to over-production of the secretion of the anterior part of the pituitary in youth, before the long bones had ended their growth in length. Note the disproportionate length of his limbs and extremities. The dwarf (only 2 feet 4 inches high) is of a well-marked type with relatively large head.

remedy has made it possible to rear sheep in the American State of Michigan, where, owing to lack of iodine in the soil and water, they were formerly unable to live. On the other hand, healthy people may make too much thyroxin if given excess amounts of iodides.

Another gland with important internal secretions is the pituitary, which produces at least two different substances. The posterior part produces a hormone, pituitrin, which affects smooth muscle. It seems to be needed for the normal function of the capillaries, which become relaxed and leaky in its absence, while the kidney produces large amounts of a watery urine. It also has a powerful effect on the womb, and is used to help it to contract during childbirth. The anterior part of the pituitary is concerned in regulating growth. When it is removed we get a dwarfish condition, and when it is enlarged and secretes too much we get overgrowth. The precise effects depend on age. In a child, a long bone, such as the femur, consists of three parts, the shaft, and two bony pads at each end, called the epiphyses. Growth takes place not at the joints but at the soft cartilaginous junction between the shaft and the epiphyses. If the pituitary begins to over-secrete *before* the epiphyses have been joined by bone to the shafts, the patient becomes a giant; if *afterwards*, he becomes only a little taller, but the epiphyses, lower jaw, brows, and some other bones grow in thickness, and a condition called acromegaly results, characterized by large hands and feet and a peculiar facial expression. Clearly for normal health the pituitary, like other glands, must produce just the right quantity of its internal secretions (Fig. 36).

The adrenal glands, which lie just above the kidneys, also consist of two parts. The central part secretes adrenalin, a substance which produces the same general effects as stimulating the sympathetic nerves; for example, a rise of blood pressure, a slowing down of the movements of the gut, and a pouring of sugar into the blood. Adrenalin seems to be constantly entering the blood, but in larger quantities during emotion. The outer part (cortex) of the adrenals is necessary for life, and probably pours something into the blood, but we do not know what. The parathyroid glands, which lie in the neck in or near the thyroid, also produce an internal secretion which regulates the amount of calcium in the blood plasma. The gonads also produce internal secretions, which control the appearance of the

secondary sexual characters which distinguish the two sexes. For instance, they act on the nervous system, and cause the appearance of the instincts connected with sex. They also influence the growth of the skeleton and other structures, such as combs and spurs in fowl, horns in deer, and the larynx and beard in man. At the time of writing one of their internal secretions has been obtained in a fairly active condition, though not yet pure.

If we take a few living cells from an organ, and grow them under the best possible conditions, usually in plasma to which have been added extracts of embryonic tissue, they will continue to divide indefinitely if they are protected from bacteria. Cells from a chicken's heart have grown in this way for over ten years, a few being transferred to fresh fluid every two or three days. It appears probable that they could be grown indefinitely in this way, so that in the body their death with the natural death of the fowl by old age must be due to causes outside themselves. Blood contains substances which encourage cellular growth, and others which check it. As an animal grows up the former decrease in quantity. One cell may produce a substance which stimulates another type of cell. Thus a healing wound is full of leucocytes, which crawl into it from the blood-vessels. As these die they liberate a stuff which causes another kind of cell, the fibroblast (which produces connective tissue), to grow and multiply, as can easily be shown on a tissue culture. The fibroblasts in tissue near the wound therefore grow out into it, forming tough fibrous scar tissue.

Sometimes growth regulation breaks down, and the cells of some part of the body grow too quickly, causing a tumour. This may be harmless, like a wart, but if the growing cells migrate into the surrounding tissues and finally to distant parts of the body, the growth, which is then called a malignant tumour, or cancer, is very deadly unless it is removed when still small. We do not yet know exactly why cells become cancerous, though in some cases this condition is undoubtedly caused by chronic irritation, for instance, by tar in tar workers, by certain parasitic worms in rats.

One of the most important functions of the blood is to clot. If this does not happen, as in certain diseases, a man may bleed to death from a tiny scratch. Blood does not clot in the blood-vessels, even if they are removed from the body, and clots only very slowly in well-greased

receptacles. But contact with broken cells or with most foreign bodies leads to clotting; in the latter case apparently because they cause certain of the formed elements in the blood to burst. At least four substances are concerned in clotting. The clot is mostly made from fibrinogen, a protein dissolved in the plasma, but at least three other substances play a part, namely, calcium (lime salts), a protein called serozyme, and a waxy substance called cytozyme produced by the breaking up of cells. It is still uncertain exactly how they interact, but interference with any of them will stop the blood from clotting. For example, a little sodium or potassium oxalate will precipitate all the calcium of blood as calcium oxalate, and thus keep the blood fluid.

Of the other proteins in the plasma some are concerned in the defence of the body from infection, though it is possible that fat-like substances play a part too. Infectious diseases are caused by animals and plants, some of microscopic size, some, such as that which causes most common "colds," too small to be seen with a microscope. One of the best known of the visible ones is the bacillus which causes diphtheria. It grows in the throat, which it may occasionally obstruct, and does not usually spread to other parts of the body, but liberates into the blood a poisonous protein which is particularly dangerous to the heart. If a man has had diphtheria this protein, called diphtheria toxin, is no longer poisonous to him, and what is more, if some of his blood is mixed with the toxin, it renders it harmless when injected into someone else. In practice one injects ground-up dead diphtheria bacilli into a horse so that it develops antitoxin without having had a sore throat. Its blood now contains antitoxin and will protect human beings against the toxin. We do not yet know the exact chemical nature of the toxin and antitoxin, but we know a great deal about them—for example, in what liquids they are soluble and at what temperatures destroyed. We also know that the antitoxin puts the toxin out of action by forming a rather loose compound with it. Unfortunately, few bacteria kill us in the rather simple way employed by the diphtheria bacillus, so few diseases can be cured by antitoxins, although they are quite effective against snake bite.

Another type of immunity is that developed to typhoid bacilli. The serum of a man who has had typhoid, when added to a suspension of typhoid bacilli in water or salt solution, makes them stick together

in little clumps and cease to move about. The same or similar substances increase the capacity of the white corpuscles for digesting the bacteria, while others will actually cause foreign cells to break up. These substances are mostly very specific, and a serum which is fatal to one race of bacteria will not always kill a very similar race which produces a disease of the same kind, still less those which cause a different disease. Besides such "immune bodies" in the blood serum which can be transferred from one man or animal to another and experimented with in tubes, the cells of organs can develop immunity which, of course, cannot be transferred, and as to whose nature rather little is known.

In many diseases most of the symptoms are due to changes in the blood composition, which affect organs remote from the one which has first been injured. For example, in heart disease the first symptom is often faintness after exercise. This is because the damaged heart cannot pump blood fast enough through the lungs to absorb the oxygen needed by the body, so the brain does not get enough oxygen. Many of the symptoms of lung diseases such as pneumonia are also due to oxygen-want. When the kidneys are diseased they cannot get rid of substances with their usual ease, and they also let the proteins of the plasma leak out into the urine. Some victims of kidney disease get headaches, vomiting and convulsions as the result of the accumulation in the blood of various poisonous substances which a healthy kidney can get rid of, others swell up and get dropsy because the kidney cannot get rid of water and salts. In most acute diseases the blood seems to contain poisonous bodies of unknown nature which upset the temperature-regulating centre, and so cause fever.

Since bacteria and other living producers of disease were discovered we have been enabled to prevent many infectious diseases. For example, we prevent the spread of typhoid and cholera by seeing that their bacilli do not get into drinking water. Malarial fever is spread by mosquitoes, which suck up from the blood the protozoa that cause it, become infected themselves, and infect the next man they bite by means of their saliva, the protozoa having multiplied and migrated into the salivary glands. Malaria can thus be prevented by killing off the mosquitoes. But, apart from surgery, rest, good diet and nursing, we can often deal with disease by means of drugs. Among the most

important drugs are antiseptics, which kill off bacteria in infected wounds or abscesses, and anæsthetics, which allow the surgeon to remove diseased organs painlessly. Some drugs, such as Epsom salts act in the gut, but most of them have to be absorbed into the blood before they act. One group of drugs are valuable because they are more poisonous to parasites than to human beings. For example, a dose of quinine which will kill almost all the malarial parasites in the blood stream only gives the patient a slight headache. But most drugs are valuable because they act on some special organ. For example, there is a form of heart disease in which the auricles, instead of beating, twitch in an irregular way. The ventricles are constantly being excited by the auricles; they therefore contract so often that they have no time to fill up between beats, and become fatigued. We give the patient digitalis, a drug which acts mainly on the heart, and in some way blocks the conduction of impulses from the auricles to the ventricles. The latter then begin to beat at a slow rhythm, but fill up properly between beats.

Again, in chloroform or ether anæsthesia there is a danger of the heart stopping, so we want to block the passage of inhibitory impulses from the brain down the vagus. For this purpose we inject a little atropine. This has the property of stopping the action of the parasympathetic but not of other parts of the nervous system. It not only hinders the action of the vagus on the heart, but also on the stomach, and this discourages vomiting. Many drugs act especially on the brain. Some affect those parts which are concerned in consciousness, and produce sleep or wakefulness as the case may be. Others affect specific centres, such as the heat-regulating or vomiting centres, and by a suitable use of them we can allay pain, fever and other symptoms which involve the activity of the brain. It is, however, certain that many more chemical weapons in the war against disease remain to be discovered.

To sum up, not only the normal activities of the body, but even its normal shape, depend on the simultaneous normal activities of its various parts. They influence one another partly through the nervous system and partly by mechanical means, as when a bone grows in response to the pull of a muscle, but very largely by chemical factors. The chemical side of the relationship between the hundred million

million or so cells that make up your or my body is sufficiently complicated, but it is simple compared to the chemistry of the reactions between the hundred million million molecules that make up a cell of average size. The study of those reactions is the main task of biochemistry. Suffice it to say that we have begun to isolate many of the intermediate products of metabolism and the catalysts that govern the course of the reactions by which they are formed. But the life of every individual cell is in its way as complex as that of the whole body, in the description of which we have taken the individual cells for granted.

CHAPTER NINE

SOME POINTS IN THE PHYSIOLOGY OF DEVELOPMENT

IN THE LAST few chapters the existence of the fully grown animal or man has been taken for granted, and the attempt has been made to discover as much as possible of its way of working: we have been studying the physiology of adult life. But the adult animal (and plant, for that matter) is not a ready-made article—it has to develop. In the second chapter we studied development as revealed by simple observation. But that gave us no more than does a mere description of structure for the adult organism. We want to know something of the physiology of development just as much as of the physiology of adult life.

The great difference between the two branches of physiology is this—that while adult physiology is dealing with stability, developmental physiology is dealing with change. In the former case, the general characters of the organism, in spite of alterations in detail, remain the same over long periods of time; and one of the most prominent features of the processes of adult life is that, as a whole, they constitute a self-regulating system, in which any excess in one direction automatically brings into play forces acting in the opposite direction. But in developmental physiology, the organism is always passing from one phase into another, and even if some of the phases—like the tadpole stage of the frog—are of comparatively long duration, yet processes are always at work which at length will upset the self-regulative power of the system, and will make it change into something quite different.

Besides these processes of normal development, however, others of the same general type may occur as the result of special circumstances. The facts of regeneration, for instance, come under this head; and, as a matter of fact, some analysis of regeneration will be found to give the best starting-point for a discussion of developmental physiology in general.

Regeneration is not a very familiar fact to most of us, since it is present to a very slight degree in ourselves and in the animals we

know best. But worms or polyps, or indeed most of the lower animals —if they could think—would find regeneration the natural, normal state of affairs, and the absence of regeneration a sad and abnormal failure. In a sense they would be right. Regeneration does at least seem

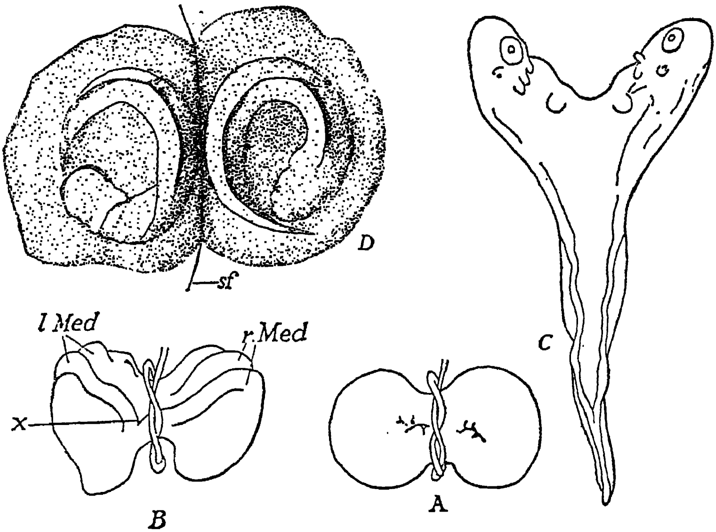


FIG. 37. Partial and complete twinning artificially produced in newts. (A) Gastrula stage after a hair has been tied round the segmenting egg so as to produce light constriction. (B) Neural-fold stage of the same embryo. Two sets of neural folds (*l.Med* and *r.Med*) have been produced anteriorly; they join posteriorly at *x*. (C) The same just before hatching; a two-headed monster has been produced. (D) Result of complete separation of the first two blastomeres by a hair, *sf.* Two healthy embryos, complete except in size, have been produced.

to be a fundamental and original property of life, lost late and for special reasons.

If you throw crumpled paper into a freshwater ditch, or set traps consisting of a bottle with boiled earth-worm for bait, you will probably succeed in catching large numbers of various kinds of freshwater Planarians—little leaf-shaped creatures of carnivorous habits and gliding movements. Choose out the brown and black species, which are the hardiest. Transfer one to moist blotting paper, and with a sharp

knife cut it clean across. The experiment sounds cruel; but in reality you will have artificially encouraged the multiplication of the species. Each of the bits, replaced in water, will regenerate what is lost and so become transformed into a complete worm. The same would have happened if you had cut the animal into half a dozen cross-pieces instead of two, and equally whether you cut it down the middle or across. If you persisted, you would discover two main facts in the course of your experiments—that any piece of any shape, provided it was above a certain quite small size, is capable of regenerating into a whole animal; and that this happens equally whether the regenerating pieces are fed or not (Fig. 40).

The same would have been true if instead of a Planarian you had cut up the little polyp Hydra, and almost the same with the smaller Annelid worms such as Lumbriculus. The same also holds for the microscopic single-celled Protozoa, although here the operations are much more difficult owing to the animal's small size.

It is also true for the very early stages of development in many kinds of animal. In a newt either of the two first cells produced in segmentation may, if artificially separated, give rise to a whole embryo; the same holds in many animals for any one of the first four cells, or for most fragments of the late segmentation and blastula stages (Fig. 37).

Thus regeneration of the extreme type—what we may call complete regenerative capacity—is found in the simplest types of animal and the earliest stages of development. It must therefore be thought of, not as a special property developed to meet the rare contingency of losing a limb or being bitten in two, but as something natural to living things, and present unless circumstances forbid it.

Further facts confirm this view. In animals of a rather higher grade of organization, such as the more complicated worms, crustacea, some insects, and some molluscs, the power to regenerate is still present, but it is limited. No longer can the animal be cut in half, or into a number of little bits, without losing its capacity for life; but so long as certain central and essential organs remain at work, very considerable losses, such as those of a limb or a tail, can be replaced. This degree of regenerative power continues even into the land vertebrates. Although the frogs and toads do not, the lower or tailed amphibia still possess it. Even a mature newt or axolotl can grow not merely a new

toe or new foot, but can repair the loss of a whole hind-limb and limb girdle. This we may call organ regeneration. In such animals, the early stages in development of an organ such as a limb are capable of complete regeneration. Thus, by cutting a tadpole's limb buds so that a number of separated bits are left, the animal may be made to grow more than the normal complement of legs (Fig. 38 and Plate 15, (i)).

The same limitation of regeneration is seen, as might be expected, during development also. For instance, while the amphibian in its segmentation and blastula stages has an almost complete regenerative capacity, the tadpole can only regenerate single organs, and the frog can do no more than heal wounds. Even in newts and salamanders regeneration is much more rapid in the tadpole than in the adult.

Among reptilia, lizards are the only animals which possess even the power of organ regeneration, and in them it is confined to the tail. When we look closely we find that here the original general power of regeneration inherent in living things has been retained in this organ for particular biological reasons, and has been combined with special adaptations to make it of greater value to the animal. The lizard has the power of self-mutilation (or *autotomy* as it is often called). If you catch a common lizard by the tail you will find that after a moment or two of squirming, the tail, broken off short at the root, will be all that you have in your hand, and the rest of the lizard will be running off into safe hiding. This is only made possible by a special structure of the vertebræ of the base of the tail; they have a crack on either side which penetrates almost to their centre, and the tail muscles are so arranged that when one set of them contracts they pull at the further half of one of these vertebræ, and snap it off across the plane of weakness.

The tail when broken off is, though doomed to death within a few hours, not yet dead; and it continues to execute the most violent wrigglings and jerkings for some time. In nature what occurs is apparently as follows: When a bird or other enemy makes a pounce at the lizard, it will often only succeed in catching it by the tail. When this happens, the tail is broken off, and by its squirmings continues to keep the attention of the attacker while the lizard itself is making for safety. The tail is lost and devoured, but the lizard grows a new one. If lizard-eating animals were rational they would probably confine

themselves to tails, gathering the annual crop as we gather the annual crops of fruit off a fruit tree. In any case, the lizard often saves itself by sacrificing its tail (*how* often could be established by finding out how long tail regeneration takes, and then by examining a number of lizards from one locality and noting how many were in process of

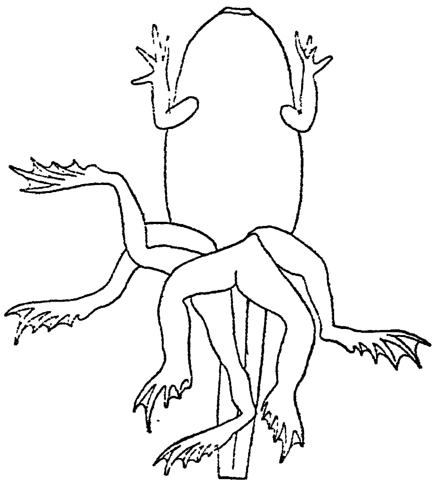


FIG. 38. Ventral view of a metamorphosing toad (*Pelobates*) with six legs. This condition was brought about by cutting into the early limb buds, each separate piece developing independently.

growing new tails—an experiment well worth trying); and this desirable end has only become possible by adding the special mechanism for breaking off the tail to the primitive power for regeneration.

Crabs and many other arthropods have this power of autotomy in their limbs, and some worms when handled break their whole body into fragments, each one of which will regenerate into a complete individual!

One word about the power of regeneration in mammals and ourselves. Although we cannot grow new limbs, yet our wounds will heal, and this is still a real regenerative process; we may call it wound healing or tissue regeneration. It is also to be remembered that in a

certain sense the growth of such tissues as the epidermis is a continual regeneration—for something is continually being lost, and as continually being renewed. These last processes fall under the head of *normal* or *physiological regeneration.* A more striking example, perhaps, than the skin is to be seen in the antlers of deer—two masses of bone weighing several pounds which are shed and renewed each year.

Two or three general principles emerge from these facts. The first—to recapitulate—is that regeneration is a primitive property of life. Most low organisms never stop growing, and the capacity for regeneration is clearly associated with the capacity for growth, since growth is necessary for many of the processes of regeneration. Other changes that are at work in regeneration, however, have the character of rearrangements; for instance, in the formation of a whole newt out of one of the first two blastomeres of the newt's egg, the only process is one of regulation—of rearrangement of material which ought to have produced a half, so that it actually produces a whole of half size. In the regeneration of a small piece of Planarian to form a whole worm, a certain amount of new growth takes place at the cut ends of the piece, but many of the changes involved are brought about by changes in the original piece. For this to happen, however, a certain degree of plasticity is needful—cells and tissues must be capable of altering their original character and adapting themselves to new conditions. This also is largely a property of actively growing organs; further, it appears to be impossible if tissue differentiation has reached too high a pitch.

Thus the gradual limiting of regenerative capacity which we find as a general rule both in the development of the individual and in the progress of life as a whole, is due partly to increased differentiation, partly to the fact that the higher animals, instead of growing indefinitely, show a sharply marked stoppage of growth on reaching the adult state.

Regeneration is thus essentially the restoring of typical form, structure, and function; we might call it a special case of regulation.

The fact that a piece of Planarian without a mouth can yet regenerate head and tail is obviously interesting. The piece's capital can be readily transformed into cash for the undertaking of new enterprises—in other words, the living framework of its body can be broken

down into food materials which can then be used up in new growth elsewhere. In the higher animals, the living capital is locked up in non-negotiable forms to a much greater extent, although not so completely as is often imagined.

This power of drawing upon the living tissues in case of need leads on to another remarkable power of Planarian and other low types. If an intact animal of this sort is starved, it can continue to exist for periods of weeks and months by thus liquidating its capital for its day-by-day expenses. Since it draws on its own tissues for its daily energy needs, it therefore must grow smaller and smaller. Planarians can continue this economical process until they have diminished their size to below that at which they hatched from the egg. If they are given food again (at any stage in the proceedings) they will start growing once more, and recover their normal size and appearance (Fig. 39).

One very curious fact was early noted about Planarians thus reduced in size by starvation—namely, that their proportions gradually altered from those of the adult and became more like those of normal young worms. This led to the idea that perhaps they not only *looked* young, but had really *become* young again—an idea which was easily put to experimental proof.

Some species of Planarians reproduce mainly asexually by transverse division; after the worm has reached a certain length a new head is formed a little behind the centre of the body, and in front of this a split appears along which separation eventually takes place. A brood of worms from one such species was taken. When they had nearly reached full size, they were divided into two lots. One lot, fed regularly, continued to grow and divide in normal fashion. The other lot was starved until the average size of its members was reduced to about half; then it was fed until it had recovered its original size; then starved again—and so on repeatedly. The experiment was continued for a period of time in which the well-fed animals went through nineteen generations (a period which, though only occupying a few months for Planarians, would in human beings mean about six centuries—from Chaucer's time till today). During the whole of this period, none of the other lot reproduced at all, but all remained within the limits of size set for them by the experimenter, and, what is more, showed no signs whatever of age or of diminished vigour. In fact

there is every reason to suppose that the experiment could have been continued indefinitely—in other words, that the individual Planarian, by proper treatment, can be made immortal.

The elixir of life was sought by the alchemists of medieval Europe for hundreds of years. These experiments show that it has at last been discovered; but, unfortunately, it is only effective with Planarians and some other animals, all of a low grade of organization.

Before we go further into the principles involved in this matter, we must mention that there is another way in which animals may surmount starvation and other unfavourable conditions.

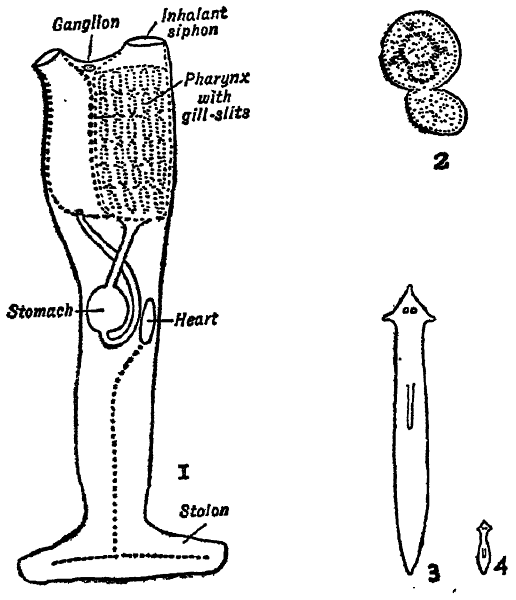


FIG. 39. Dedifferentiation and reduction. 1 and 2, the Ascidian (sea squirt), Clavellina; 1, normal; 2, the same individual dedifferentiated after exposure to adverse conditions; 3 and 4, the Flatworm, Planaria; 3, normal adult; 4, the same individual after several months without food.

If an ordinary hydroid polyp like Obelia be kept in the laboratory, the hydranths, or separate organized individuals of the colony will, (unless the water is well aerated artificially) show a curious series of

changes. Their mouths will close and their tentacles become stumpier; eventually they will lose almost all signs of their previous differentiated structure and become converted into a rounded or egg-shaped bag with a few little knobs marking where the tentacles had once been. They have lost differentiation—in other words, have undergone dedifferentiation.

In Obelia the process is complicated by the fact that while dedifferentiation is going on, the cells of which the hydranth is made up detach themselves from their neighbours and, leaving their fixed place in the tissues, migrate into the central cavity and down into the common stalk which connects all the hydranths. By this means the hydranth dwindles rapidly, and is reduced soon after dedifferentiation is complete, to a tiny knob in the bottom of its protective horny cup. The animal has been resorbed by the stem. It is as if a house were to be unbuilt, by the bricks leaving their places in the walls and migrating into the garden.

If, however, the hydranth is cut off at its base beforehand, the central cavity is soon filled up with detached cells, and after this, dedifferentiation alone occurs until the animal is reduced to a mere living bag tight packed with cells. These types of dedifferentiation are found in many low types of animals, such as various Cœlenterates and Ascidians (Fig. 39).

Among higher forms partial dedifferentiation may be a normal mode of development. For example, when the tadpole metamorphoses into the frog, some of its tissues start to dedifferentiate, for instance, those of the gills and tail. The process is complicated by the fact that phagocytosis, or the devouring of undesirable materials by white blood cells, here reaches a far greater pitch of perfection than in lower animals, and, as a result, as soon as the cells have reached a certain degree of dedifferentiation, they are attacked and removed by the white blood cells. The disappearance of the tadpole's tail is thus due more to the activity of the phagocytes than to the migration of the tail cells themselves. Similar methods of resorption of tissues are found when, for instance, a tumour or a graft disappears in a human being.

To return to regeneration, and to another of its aspects, it is found that the presence of one part is often necessary for the regeneration of

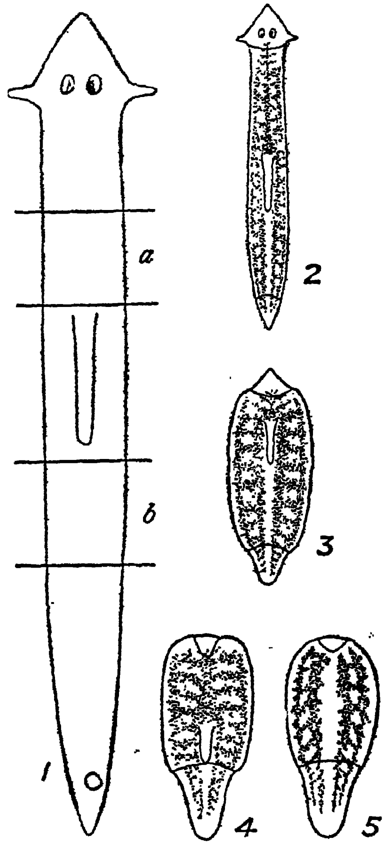


FIG. 40. Regeneration and differentiation in Planaria. 1, a normal adult worm in outline, showing eyes and pharynx; *a* and *b*, levels where pieces were cut out. 2, either *a* or *b* pieces may regenerate a new head; in this case complete differentiation to a normal worm occurs. The original pieces produce new head and tail by new outgrowths, new pharynx and altered shape by remodelling. 3, in adverse conditions, only a rudimentary head is produced. 4 and 5, in very adverse conditions, no head is formed; the front end merely forms a scar. In these circumstances, *a*-pieces form a new pharynx (4), but *b*-pieces do not (5).

another part. In Planarians, for instance, the mouth opens at the end of a sort of trunk, the muscular pharynx, which can be protruded from the centre of the underside. If a small piece of the flatworm is cut out by two transverse cuts, it depends on a number of circumstances whether a head shall be formed or not; for instance, a low temperature near freezing, or exposure to dilute alcohol or other poisons (the experiment is easy to carry out) will reduce the frequency of head formation, or even suppress it altogether (Fig. 40).

If a head is produced, such a piece will always proceed to the formation of a pharynx. But if no head appears, the formation of a pharynx depends on the original position of the piece in the body. If it was cut from in front of the original pharynx, it will often regenerate a pharynx, even in the absence of a head; but if it came from behind the original pharynx, a new pharynx will never be formed unless a head forms first. In other words, a new pharynx will be regenerated in the centre of a piece of Planarian provided that there exists at the front end of the piece a region which is normally anterior to a pharynx—whether this anterior region be an old part of the body or a new regenerated head.

Thus, the head or front region of the body exerts some remarkable influence upon a distant region of the rest of the piece, making it construct an organ that it could not otherwise produce. It makes things make themselves. Exactly how this effect is produced we do not know. Possibly it is through the agency of the nervous system. In any event, it is clearly a property of very great importance, and also one which seems to be of quite general occurrence. For instance, when the eye-stalk of a prawn is cut off, a new one like the old is usually regenerated. But when, in addition to the eye-stalk being amputated, the optic ganglion, or part of the brain to which run the nerves from the eye, is also cut out, the organ which is regenerated bears no resemblance to an eye and eye-stalk, but has precisely the form of part or all of the first antenna or feeler, the appendage which normally comes next behind the eye.

One other fact gained from the study of regeneration needs to be considered before the problems of normal development. If one of a pair of organs be removed, remarkable results often follow. For instance, in certain diseases, one kidney may have to be cut out. When

this is done, the other begins to grow, and at the end of a few months weighs almost as much as the original pair together. This enlargement follows as a direct result of the increased demands made upon the functions of the surviving kidney, and is therefore known as compensatory functional overgrowth. There is no regeneration of the missing organ, but a compensatory growth of its mate, resulting, one may say, in a *regeneration of function.*

This functional overgrowth may be found not only to compensate for the loss of one member of a pair of organs, but also when part of a single organ is removed, or when an extra demand is made upon an organ without removal of anything.

If, for instance, most of the liver or pancreas or reproductive organs are removed, the bits that are left will start to grow rapidly, until they are large enough to cope with the demands of the body.

Or, as illustrative of the second case, the normal thyroid secretion is very rich in iodine. When the amount of iodine in the food and drink falls below a certain quantity, the demands of the body for more iodine-containing secretion react on the thyroid; this begins to grow, producing more total amount of secretion as an attempt at compensation for its poverty in iodine. It may grow to a relatively huge size, producing a great swelling, called a goitre, in the neck. If a little iodine is given to a patient with such a goitre, the reverse process sets in, and the swelling is reduced* (*see also* p. 237).

A similar process takes place in muscles when extra demands are made upon them. Everybody knows how heavy exercise "develops the muscles," and, after a preliminary period of loss of weight due to utilization of the reserves of fat, make a man put on flesh. The actual size of the muscles increases as the result of exercise.

With this information we can now attempt some account of the normal development. It is found that the early development of a vertebrate such as a frog or newt falls, from our present standpoint, into three main periods. The first is essentially a period of the division and rearrangement of already existing materials, and takes the fertilized egg through segmentation and some way into germ-layer formation. The second is mainly one of differentiation—visible structure

*This is not the only type of goitre; e.g., exophthalmic goitre or Graves' disease seems to arise from quite other causes.

appears, the organs are blocked out, and tissues become different each from the other. Finally, in the third, the two most important features are growth, and the welding of the differentiated parts into a working whole—by mutual influence of organs upon each other and by an adaptation of separate organs to the demands upon them through the effects of function upon growth.

This last phase may be taken first, since it is in many ways the most familiar. Think of a young organism—a recently hatched tadpole, a puppy, a child. Although it has already a characteristic organization, yet this organization is still plastic within wide limits. The final shape and size of its bones, its muscles, its sinews and tendons, its glands, its digestive tube, even of parts of its central nervous system, depend very largely upon the amount and the kind of use to which they are put during development.

If one of a puppy's fore-limbs is tied up soon after birth so that it is never used, the dog will manage to get about very well with only three legs. But the leg which has not been used will be very different from the others. The bones of its skeleton will grow almost to the normal length, but will never attain more than about half their normal thickness, nor will the arrangement of bony struts and stays at either end of the shaft (which in an ordinary bone are developed so as to meet both vertical and sideways strain in the mechanically most perfect way) be properly formed. The muscles of the leg, too, and their tendons will be very small. Not only this, but the nerve-cells of that region of the brain which controls the movements of the limb will be undersized.

The power of bone to respond to the strains to which it is exposed, is of practical value. If, for instance, one of the small bones or phalanges of a finger is crushed and has to be removed, a small piece of bone from some other region can (if it include some of the periost layer from which new bone cells are produced) be grafted in to take its place. After a year or two the irregular splinter will have come to bear a marked, though not complete, resemblance to the bone for which it is doing duty (Plate 15, (ii)).

One of the most striking adaptations in the body is the fact that every tendon which attaches a muscle to a bone not only is of the proper size for the strain which the muscle can exert upon it, but is

composed of parallel fibres which run precisely in the region of greatest stress. How can this beautiful relation of mechanism to function be supposed to have originated by natural causes? Does not the purposeful adaptation, different in detail for each separate tendon, demand the intervention of some supernatural power?

Research, however, has in great measure removed such difficulties; for it has shown that all the separate detailed adaptations are the direct consequence of one inherent property of the tissue of which tendons are made.

If a piece is cut out from a long tendon, such as the Achilles tendon which passes from the muscle of the calf over the heel to be fastened to the sole of the foot, it will after a time regenerate. Connective tissue grows out into the wound, the cells elongate and form fibres in the direction of the tendon, make attachment to the cut ends, and reproduce a structure essentially like that which was originally present. But if by one means or another the calf muscle is put out of action (as when its nerve has been severed) then, although the gap will be filled by a new growth of connective tissue, the fibres will not become arranged in any particular direction, and no tendon-like structure will be formed.

Further, when in such an animal (the main experiments were carried out in rabbits) a piece of clean silk was healed across the middle of the wound, at right angles to the original tendon, and then, by winding it up very slowly on a screw, increasing tension was put on one end of it, it was found that fibres were formed in the new connective tissue, but parallel to the silk, and therefore useless for any restoration of normal function.

From these facts (supported by many others) it is clear that tendon fibres are formed from connective tissue when the connective tissue is frequently stretched, and further, that they are formed parallel to the stretching force. This stretching force is usually the force of muscular contraction (in growing animals there will also be found stretching due to growth of bones); so that tendons will be formed from ordinary connective tissue when muscles begin to contract,* and will be "adapted" to the direction and amount of stretching exerted by the muscle. In any case, all the apparent design seen in the adaptation of

* It is possible that they may originate in other ways as well.

each several tendon to the demands made upon it, is apparently a direct result of this one reaction of connective tissue to tension.

To sum up, we may say that certainly most of the tissues of the body—possibly all—respond either throughout life or at least during growth (while their cells are still capable of multiplication) to the demands made upon them, and respond on the whole very advantageously from the point of view of the whole animal. The skeleton, the muscles, tendons, many and probably all glands, the central nervous system—all these we have already seen to show functional adaptation. So does the skin. Everybody knows that (after the blister stage has been negotiated) continual rubbing will make the skin thicken. "Horny-handed" is so hackneyed an epithet for manual labourers as to have almost become mere journalese, and every oarsman demonstrates the fact in his own person. So, too, the circulatory system responds to functional demands. If Everest is ever climbed, it will probably be because men can become "acclimatized" to high altitudes and consequent low oxygen supply, largely, it would seem, through an extra production of red blood corpuscles by the bone marrow and in consequence a greater capacity of the blood for capturing and transporting what oxygen there is.

Furthermore, the size of a blood-vessel, both diameter of cavity and thickness of wall, is determined very largely—perhaps wholly—by the amount of blood which is pumped through it, and the pressure at which it is pumped. Cases are known in which large arteries become blocked up. If the blocking-up process is not too rapid, one or more small branches of the vessel will gradually enlarge, and produce channels capable of transporting the requisite amount of blood without difficulty. This has been known to happen even when it is the human aorta, the main and indeed the only large artery springing from the arterial side of the heart, which has been blocked.

The same kind of adaptation is also true of the protective reactions of immunity. It is a familiar enough fact that children who have had measles once do not generally catch it again, but this is only one among innumerable instances, such as the over-production of diphtheria antitoxin by horses injected with small doses of the toxin or poison produced by diphtheria germs, which has reduced the disease from a cruel scourge to a serious unpleasantness, or the benefits given

by vaccination. All these again depend on one single property of higher animals; when unaccustomed proteins enter their system, they can (if the foreign substances are not in too great amount, and provided certain other conditions are fulfilled) not only destroy or inactivate them, but in the process generate an excess of the destroying substance or *antibody*, which remains for a longer or shorter time so that a second invasion can be more rapidly and effectively crushed (*see also* p. 241).

Although many of these adaptations are possible throughout life, others can only occur during development, and most of them are essential for normal development, since only through them do the size and structure of the various organs come to correspond to their function and to the physical and chemical stresses imposed on them.

There is, however, another type of mechanism which is active through the later periods of development and plays an important role not only in this functional adaptation but also in fusing the parts of the organism into a more unified whole, and that is the endocrine system or sum total of the ductless glands (*see also* pp. 236–9).

Many of them, such as the thyroid and the pituitary, have indispensable functions as regards proper growth. The thyroid regulates the rate of metabolism, increased amount of thyroid secretion producing an increase of oxidation in the body. As might be expected, this function seems to be of more importance to the well-being of animals such as mammals, with a normal high metabolism (great heat production and constant high temperature), than to those like fish or frogs, which do not have to be constantly generating large quantities of heat to keep their temperature above that of their surroundings. Within the mammals, the absence or failure of the thyroid makes more difference to an adult man than to an adult sheep: the thyroidless sheep is but slightly abnormal, while the thyroidless man becomes notably fat, sluggish, and slow-minded. But its absence in the child, in whom growth and activity should be much greater, makes far more difference again than in the grown-up man; the thyroidless human child or *crétin* usually dies early, can only grow into a stunted dwarf, and never develops normal intelligence, the brain of man apparently requiring a high level of metabolism for its unfolding. In Amphibia, metamorphosis from larva (tadpole) to adult is under the

control of the thyroid. Tadpoles with their thyroid cut out refuse to be transformed into frogs, and grow to giant size in the water (Plate 13 (i)), while if a dose of thyroid is given to quite young tadpoles, they will metamorphose into froglets no larger than flies.

The changes which take place in body and mind at puberty are also under the control of the endocrine system. The immediate control is exerted by the gonad itself. It is important to find that a whole set of separate changes can be brought about by a single change in the ductless glands, and further, that all these changes are in the long run related to one function, that of reproduction.

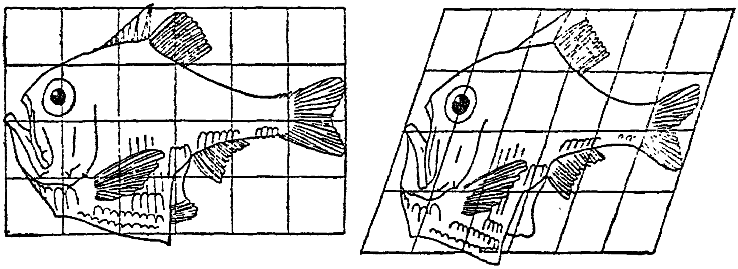


FIG. 41. Outlines of two related species of fish (*Argyropelecus olfersi* and *Sternoptyx draptiana*). The one can be derived from the other by a simple distortion of the relative directions and intensities of growth in length and growth in a dorso-ventral direction.

That a single original alteration in the chemical composition of the blood, an alteration appearing inevitably at the end of a definite span of growth, should bring about an increased growth-rate, the formation of mature spermatozoa in the testes, the appearance of hair on the face and body, and a marked change in mental outlook and temperament, is one of the most striking facts in biology.

All the ductless glands have this in common, that their secretions are carried all over the body by the blood, so that they can exercise a number of different effects simultaneously upon the most diverse organs.

It is fairly obvious, however, that for all the importance of function and of the endocrine system in development, their task is essentially one of regulating the degree of activity of processes already in being, or of directing them along particular channels. Bones exist in the absence of a pituitary or of pressure upon them, and muscles without

being used. It is only a small part of the adult man's growth of hair that is dependent upon the testis; metabolism continues in the absence of a thyroid, and the first development of a gland or blood-vessel takes place before its use begins.

Another point that should not be forgotten is that in the long run the differences in shape and size between different animals depend almost entirely upon differences in the amount and direction of growth in different regions during development. In very early life the hind-limbs of a whale grow much less fast, compared with the body, than do those of a man, and those of a man much less fast than those of a kangaroo. Some idea of the changes which would be produced in human beings if the proportions between general growth in length and growth in breadth were rather different from what they actually are, can be obtained by visiting the distorting mirrors at a fair or circus. Or one organ may be affected differently from the rest; the effect of this on general proportions may be seen by looking at oneself in the broadening mirror, first with the arms held against the sides, and then outspread at right angles to the body.

If in the embryo of the fish Argyropelecus the tendency to growth in length had been a little less, and the main direction of dorso-ventral growth were not quite at right angles to the main direction of growth in length, it would have developed into a passable imitation of another kind of fish (Fig. 41). No doubt such slight alterations in growth are at the bottom of much evolutionary change.

How do these more fundamental structures and functions originate to provide the primal basis to be shaped by the secondary moulding forces we have described ? Although much is still not clear, yet the main outlines of the answer emerge when we look at the next previous stage of development, the stage of differentiation.

This starts during gastrulation (Plate 5), and ends as the various organs become capable of functioning. Its great characteristic is the sudden appearance, in the hitherto comparatively simple germ, of a number of chemically different regions, each one of which is destined to generate one particular kind of organ. What is more, this will usually be accomplished whether the developing organ rudiment is in its proper relation to the rest of the organism or not.

If the late gastrula is cut in two so as to separate front from hind

region, each part (after healing the wound) will proceed to develop just those organs which it would have done if the embryo had been left intact. We are presented with an anterior half-embryo without any of the hinder organs, and a posterior half-embryo with tail, hind limb buds, and most of the trunk, but no head regions, gills or heart. There is, in fact, in this stage *no* regeneration whatever of missing

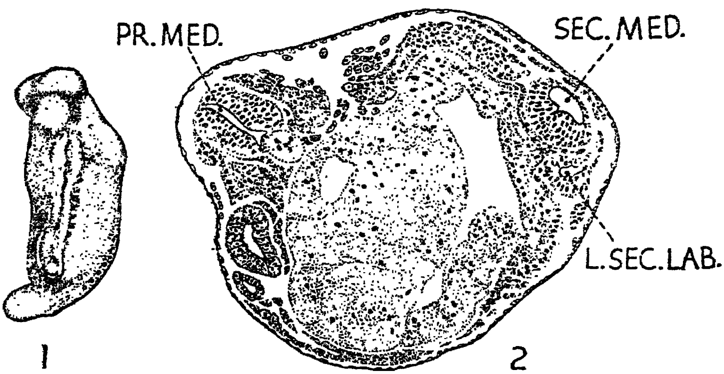


FIG. 42. To show the effect of the dorsal-lip region of the amphibian embryo in inducing development. 1. An embryo which during its gastrulation has had grafted into its flank a dorsal-lip region from another embryo. It has developed its own head (anterior), tail and nerve-tube with somites (right), etc. In addition, a secondary set of main organs has been induced in it by the graft. Of these, tail, nerve-tube and somites are visible; ear-vesicles were also formed, but not the front of the head. 2. Microscopical section through this embryo. PR. MED, nerve-tube of the host, with notochord below it. SEC. MED, nerve-tube induced by the graft. L.SEC.LAB, left induced ear vesicle.

parts; yet, in spite of this, both halves appear quite healthy, and only begin to degenerate at a stage when the organs should be beginning to work and the animal to fend for itself. Or a piece of one embryo may be grafted on to another embryo, even of a different species, and both will continue to develop (Plate 13 (ii)). One actual "chimera" has been artificially produced consisting of the front half of one kind of frog and the posterior half of another, which grew and metamorphosed quite happily.

Or if a small part of the future brain region be cut out just after the gastrula stage, and grafted in again in reversed position, it will produce

what it would have produced in an untouched embryo, although now of course the organs to which it gives rise will be misplaced. The eye, for instance, which is formed by an outgrowth from the brain (Plate 10), may by this means be made to develop behind the ear, and yet have normal structure. This will happen in spite of the fact that no visible trace of even the earliest eye rudiment was present when the operation was performed.

Before gastrulation, on the other hand, no such irreversible changes, inevitably determining the future appearance of organs, have yet set in.

Cutting the developing egg in half in the earliest stages has a totally different result from cutting it in half after gastrulation has set in. In the former case, as we have seen, one or both halves may become reorganized into a whole, and produce an embryo normal in every respect save size.

One very remarkable fact has recently been discovered, namely, that the sudden change that takes place in a few hours during gastrulation in an animal like a frog or newt, during which the germ loses its capacity for regulation and becomes a sort of jig-saw of separate parts, each predetermined to produce just one particular organ of the future tadpole, occurs under the influence of one small region of the embryo. This is the region just above the dorsal lip of the blastopore. By ingenious microscopic operations, even tiny bits of a newt's egg can be removed and grafted into other places on the same or other embryos. If this dorsal-lip region be taken and grafted into the flank region of another developing egg, it is found to cause the development of an extra set of organs, in addition to the one produced in relation to the host egg's own dorsal lip. Extra nerve-tube, notochord, muscle segments, kidney tubes, and gut may be thus induced to form—in other words, the beginnings of a whole second embryo. What is more, they are not formed by the grafted piece itself, but in the host tissues near it. Again, we are reminded of Mother Carey in Kingsley's *Water Babies*, who "made things make themselves." No other region has this power, and so the title of "organizer" has been bestowed upon the dorsal-lip zone (Fig. 42).

It is interesting to recall that a similar sort of power was exerted by the head of a Planarian in inducing the formation of a mouth and

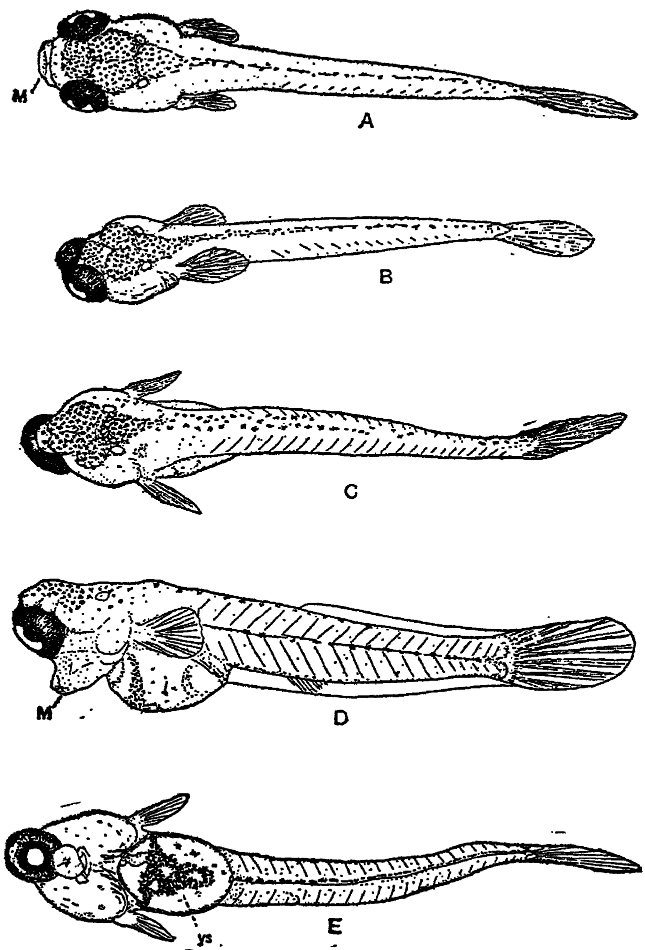


FIG. 43. Free-swimming larvæ of the top-minnow (*Fundulus heteroclitus*). (A) Normal larva, with anteriorly placed mouth, *m*. (B) Incompletely cyclopean larva, with the two eyes joined and occupying the position usually taken by the mouth. (C) Completely cyclopean larva, with single antero-median eye, dorsal aspect. (D) Lateral aspect of same, showing the ventral mouth. *m*. (E) Ventral aspect of same; *ys*, yolk sac. (From Stockard.)

pharynx (p. 255). Another fact is that the dorsal-lip region at this period is the most actively working part of the embryo, with very rapid cell division. It seems probable that this great activity has something to do with its organizing capacity.

Other interesting results, also apparently concerned with differences of activity in different parts of the developing egg, have been obtained with still earlier stages. For instance, if fishes' eggs or frogs' eggs are put for a few hours during early segmentation in solutions of magnesium or lithium chloride (or of many other substances in damaging concentrations) very curious results may be obtained. The front end of the animal, between the eyes, does not develop properly, or sometimes is not formed at all. As a result the eyes are close together, or joined up to form one eye, as was fabled of the Cyclops, or are even absent altogether. The rest of the animal develops almost normally (Fig. 43).

Conversely, if eggs are put during the same period in the right concentration of stimulating substances, such as atropin, caffein, etc., more or less the converse result is found. The whole embryo develops more rapidly than normal, but the excess rapidity is greatest at the front end, and embryos are produced with abnormally large heads and eyes (Fig. 44).

Something of the same sort may also be effected by keeping frogs' eggs between plates at different temperatures. When the yolk-cells, which are going to give rise to the belly region, are heated, and the animal pole-cells, which give rise to the head, are cooled, the tadpole which hatches out has a slightly small head and large abdomen; while precisely the opposite effect is produced if the temperature-gradient through the egg is reversed.

All these results appear to depend upon the fact that the animal pole-cells are more active physiologically than the yolk-cells, which are hampered by their stores of inert yolk, and the activity grades down from one pole of the egg to the other. The more active cells are both more susceptible to harmful agencies—hence their failure to work properly in $MgCl_2$ solutions, etc.; but they can respond better and quicker to favourable agencies than the less active yolk-cells. It looks as if we shall have to attack these very early stages if we want to obtain any marked degree of control over the processes of development.

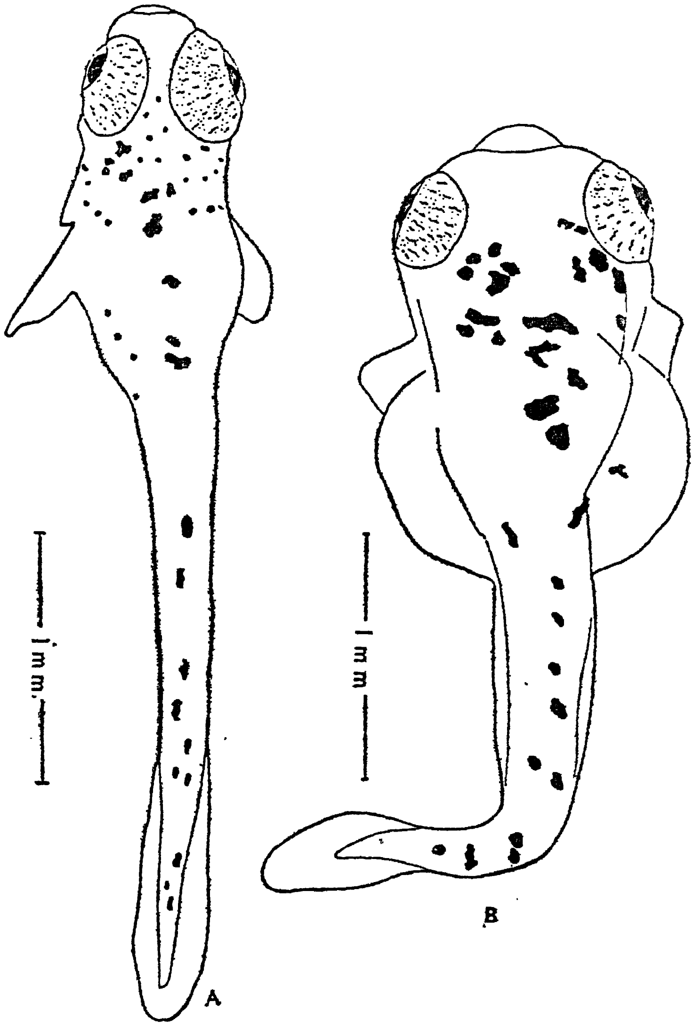


FIG. 44. Acceleration of development in the embryo of a fish (*Macropodus*) by means of exposure to atropin sulphate for one and three-quarter hours during early segmentation. (A) Control, developing in normal conditions. (B) Treated specimen. Note the much greater size of the head. Its heart-beat was also more rapid. (After Gowanloch.)

Our knowledge of these first two periods can be summed up thus. Although the period up till early gastrulation is of course an essential link in the developmental chain, no important steps in the construction of the details of the animal's typical organization are being taken so long as it lasts. The original comparatively simple organization of the zygote is not much altered; and the most essential change is the cutting up of the huge and unwieldy single cell, the fertilized ovum, into hundreds of small cells. In the first place, these are far more mechanically convenient, just as a hundredweight of bricks is suitable building material, while a single giant brick weighing a hundredweight would be useless. And then each is a relatively independent unit, with its own cell membrane as frontier, so that it is much easier to localize a number of separate chemical processes in different parts of an embryo divided up into cells than it would be to localize them if the embryo were all one large cell, in the same sort of way that the possession of a number of small pots and pans makes easier the task of preparing an elaborate dinner.

To choose another parallel from human affairs for the second and third phases of development, we might say that the second corresponds to the discovery and invention of new processes, new machines, new products, while the third corresponds to the growth of the industries based on these discoveries, a growth which is regulated by the laws of supply and demand, by the customs and laws of the country, and by the state of world affairs, but can only take place once the new inventions have been made.

In conclusion, it is worth mentioning that every cell of the body appears to receive the same complement of chromosomes, the original set possessed by the fertilized egg being exactly duplicated at each cell division, so that each cell has a "copy" of it. This at first sight seems to make differentiation hard to understand; but perhaps a musical analogy will make it clearer. The performance of a piece of pianoforte music demands a pianoforte. But we might have a hundred identical pianos in a row, from each of which would be emanating a wholly different piece of music: that would depend upon the players.

For the pieces of music substitute the different organs of the embryo; then the pianos are the chromosome sets and the players are represented by the different conditions in different regions. For instance,

at the close of segmentation some cells are small and poor in yolk, those at the opposite end are large and yolky, some are at the surface, others tucked away in the interior; and the differences between different parts are increased after gastrulation.

In animals progressive development generally comes to a close with the attainment of the adult condition. In man, however, this need not be so in respect of one character. Mental development may continue; in other words, the contents of the mind may increase and its organization become more complex and more perfect, so long as maturity continues and senility has not set in.

Of course this is by no means always very marked, and equally of course something of the same kind is seen in the higher vertebrates which can profit by experience. But the extent of the possible development open to man is none the less very striking. One of the chief biological differences between man and all other organisms is that, through his power of thinking and learning, his development and differentiation can continue through the whole of life.

CHAPTER TEN

THE METHODS OF EVOLUTION

IN THE LAST few chapters we have begun to learn something of the extraordinary complexity of our bodies. What appear as the simplest of actions are often dependent upon a delicacy of mechanism not to be found in our man-made machines, while many human faculties could never exist without the foundation of a whole series of carefully adjusted living processes. Human thought is only possible within narrow limits of temperature. Our brains will only work even approximately well within a range of about 3° or 4° centigrade, and to keep the blood at constant temperature requires the elaborate machinery, which we have already discussed, of sweat glands, dilating and contracting blood-vessels, and their nerve supply. Or again, merely to pick up a pencil from the floor or a cricket ball from the grass requires first of all an exact judgment of distance, which means a connexion and co-ordination between the brain processes involved in sight and the judging of seen objects, and those involved in the sense of muscular movement and judgments of muscular movement; and secondly, the co-operation of a large number of separate muscles in body, arm and fingers, each of which has to be made to contract or relax just so much, no more and no less, by nerve impulses of just the right number and frequency.

How is it possible that this complexity can have come into being?

At the outset we must remember that it *does* come into being in every one of us during the first few years of our life. Each one of us started as a formless germ with hardly any differentiation—no separate organs or tissues, no sense organs, no brain, no capacity for regulating its temperature, for moving from place to place, for thought. Something (and a great deal too) had to be formed out of next to nothing before we were ready to be born. Even after birth we had to learn to do a great many things that we take for granted, such as judging the shape of things from sight or even from touch;* learning

* The well-known experiment of crossing the index and middle fingers and finding that a pencil, a pellet of bread, or the tip of the nose, when between their crossed tips, is felt double, shows that the judgment of solidity from touch depends largely upon the proper association of sensations from different regions—such as finger-tips. In making judgments that a ball is spherical, we are doing something still more elaborate. The shape of the visual image, and its shading, have

to control our muscles accurately. Have you ever watched a baby making bad shots for its mouth, or at some bright object in front of it, learning to walk, to speak? A new-born baby is even more helpless in many ways than it seems. Its brain cells and fibres are not fully developed, and it is not for some weeks that it is even capable of beginning to learn many types of lessons. The power of the centres in the cerebral cortex to combine the raw materials provided by the sense in proper relation is well seen in the following experiment. A man was provided with inverting lenses, so that he saw everything upside down. By wearing them all day for a week or so, however, he gradually came to make the right associations quite unconsciously between the inverted vision and his bodily movements. It is in a similar way that the baby must learn to associate its visual and tactile and muscular sense impressions, for they are all equally arbitrary, and only by association can the relation between them be worked out by the brain.

There has thus been real evolution in the individual development of every human being and higher animal or plant—an evolution that is accessible to everybody's observation.

The other evolution, that of one species out of another, one whole type of animal life from a lower type, cannot generally be observed in this direct way. If the evolution of the individual is as easy to watch as the movements of the second hand of a watch, that of the race is as impossible of direct detection as the movement of the hour hand.

Various facts, however, as we have already pointed out, make it impossible to get on without assuming that racial evolution has occurred; and further, when we examine fossils at huge intervals of time, we find that change has taken place. In just the same way the undetectable movements of the hour hand are made visible if we note its position only at half-hourly intervals, and the far slower geographical movements, such as the erosion of the Norfolk cliffs, or the building out of Dungeness into the sea, can also be detected if measurements are taken only at intervals of a few years. Occasionally, however, we can trace the actual evolution of one species out of another in the fossils which they have left behind in the rocks.

to be associated with memories of the feel of similar objects previously seen. A man who had been blind from birth would have, like a baby, to learn to see things solid.

However, even if we can be sure that evolution has occurred, that our own bodies and minds are derived by slow descent from those of ape-like creatures, those from lower mammals, those again from reptiles, amphibians, some form of fish, and so back till at the remote start we had traced our pedigree back to a single-celled creature—however certain we can be of the facts, our certainty gives us no answer to the question of how the facts came to be so—the machinery by which evolution works.

There have been several main theories as to the method of evolution. The first is called the Lamarckian, after its author, the French

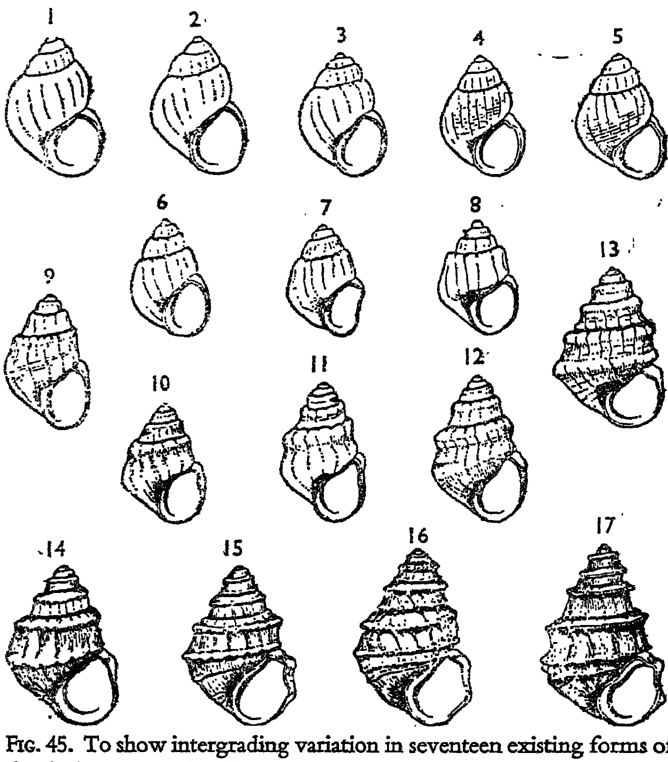


FIG. 45. To show intergrading variation in seventeen existing forms of the freshwater snail *Paludina*, from various localities. The extremes would be regarded as distinct species if they were not connected by a complete series of intermediate forms. Similar gradual variation is often found during geological time. (Lull, *Organic Evolution*, 1922.)

naturalist Lamarck (1744–1829), the second the method of Natural Selection, first clearly set forth by Charles Darwin (1809–1882).

The first assumes that changes produced during the life of the individual, whether by direct effect of the external environment, or by voluntary or involuntary use and disuse of its organs, are inherited; and that these inherited changes accumulate in the course of generations so as to become fixed. Characters acquired in this way during life are usually called *acquired characters*, or sometimes simply *modifications*. If, for instance, a tame sea-gull is fed on corn instead of fish, the whole lining of its stomach alters, becoming thicker and more like that of seed-eating birds. Or, again, the proper sort of exercise actually causes muscles to become larger. In hard training, although at first a man's weight will go down, because the fat gets used up as fuel, yet afterwards his weight will go up again, this time owing to the building of new muscle tissue.

The Lamarckian theory would have it that the effects of changes like these are perpetuated in the offspring; thus the direct action of external conditions, or, as we usually say, of the animal's environment, would be one chief cause of evolution, and the habits and will of the animal the other chief cause.

However, there is little or no evidence for the theory, and a great deal against it. We will take a particularly striking example from botany. Many plants grow both high up among mountains and down in the plains and valleys. Those which grow higher up must exist in lower temperature, longer winter, more violent weather, poorer soil. As a result, they grow into a shape quite unlike that of the lowland variety. The dandelion, for instance, when growing in the Alps (Fig. 46) is a dense rosette of small leaves, a long root, and a short flower stalk; in the lowlands, as we all know, its stalk may be long, its leaves large and spreading, its root (though too long for the gardener) much shorter.

If dandelions from the Alps are taken down and grown in the plain, all their new growth is of lowland type, and in a short time they become indistinguishable from lowland dandelions, while exactly the reverse is true of lowland plants transplanted to the Alps. The same is true when seeds of the Alpine type are sown in the plains, and vice versa. The time spent in an Alpine environment has not

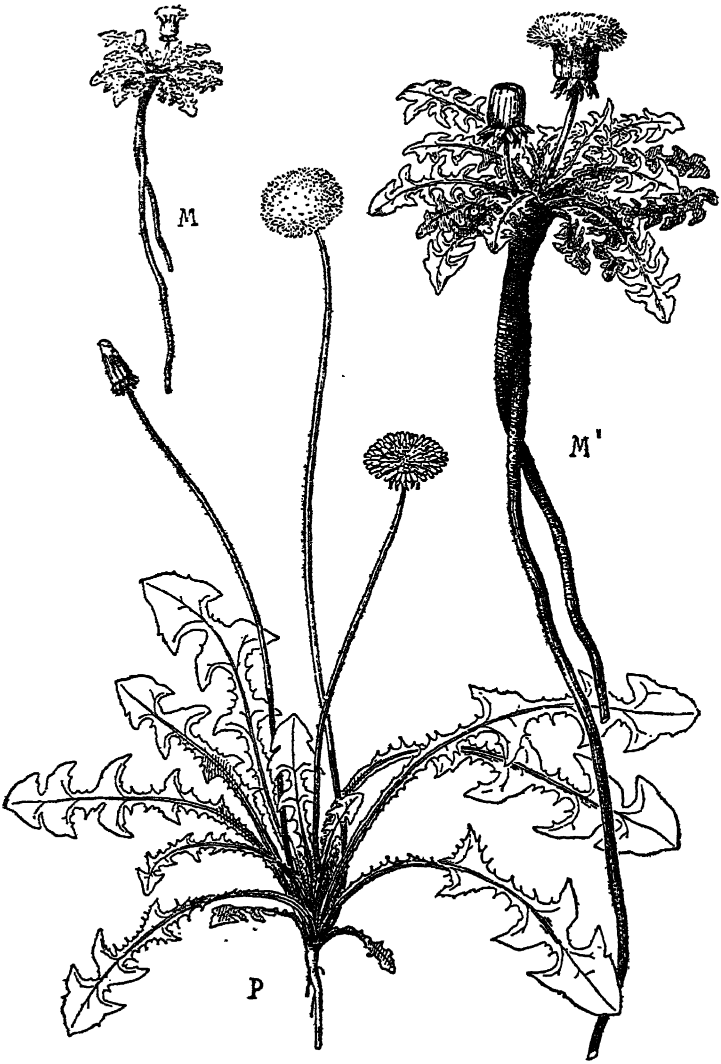


FIG. 46. Modifications in the dandelion (*Leontodon*) produced by differences in the environment. (P) Lowland form from rich land. (M) Result of growth in high alpine surroundings, on the same scale. (M′) The same, more highly magnified.

in the slightest degree finally fixed the Alpine habit of growth.

This can be readily understood if we suppose that the dandelion has a fixed constitution which, however, reacts differently to different external circumstances; it has, that is to say, a fixed capacity of being modified in special ways. This is obviously true for simple chemical substances. One particular sort of paraffin, for instance, melts at, say 61°, another at 62° centigrade. Keep the former in one environment —below 61°—and it stays solid; keep it above 62°, and it stays liquid. But you will not make it raise its melting point however long you keep it melted. The two will continue to show their characteristic modifications in relation to heat—their original melting points—as long as you like to keep them. To take another example, this time from the animal kingdom, attempts have been made to explain the black colour of the negro as the accumulated effect of generations of sunburn. It is of course true that most white men in a tropical climate become sunburnt;* the strong sunlight has a direct effect in causing more pigment to form in the skin. But anybody can verify for themselves the fact that the children of men tanned in this way are not noticeably less white than those of parents who have never left England.

What does this imply? Surely, that European and negro have different constitutions as regards skin colour. The European stays pale in temperate countries, darkens in the tropics. But the negro is black wherever he lives. We can go back to our previous comparison; we can think of two grades of paraffin, one melting at 65° centigrade, the other at 40° centigrade. The first, if kept in the shade, will remain solid throughout the summer in any region of the earth; but the other, though it would stay solid in an English summer, would be liquid in the tropics (*see also* Fig. 47).

This interpretation would clearly leave no room for the Lamarckian theory, and, as time has gone on, more and more of the examples that the Lamarckians claimed as proving their point have been shown to be explicable in some such way as this.

The further difficulty remains that we are ignorant as to *how* the inheritance of acquired characters could be brought about.

* Although some very clear-skinned people, like certain Scandinavians, only get red and inflamed.

Every animal, as we have seen, consists of a number of organs concerned with the working of the individual, together with the reproductive cells whose primary function is the perpetuation of the race. To the first, taken together, the term soma (the Greek for body) is applied, while the second is called the germ-plasm. The soma is of necessity mortal, while the germ-plasm is potentially immortal, and

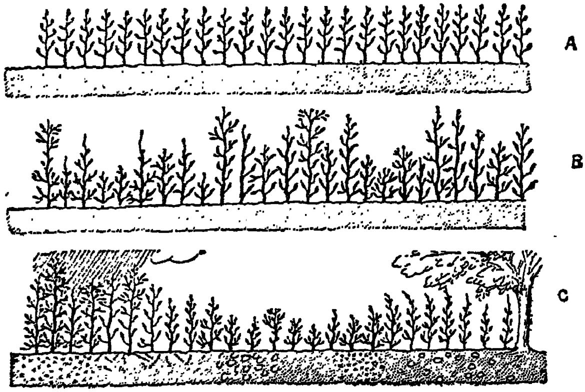


FIG. 47. Diagram to illustrate the effects of differences in environment and in constitution upon differences in visible characters of organisms. (A) Plants, all of similar hereditary constitution, grown under uniform conditions of environment: result, similarity. (B) Plants of various hereditary constitution grown under similar conditions of environment: result, diversity, due to mutation or to recombination. (C) Plants, all of similar hereditary constitution, grown under various conditions of environment: result, diversity, due to modification.

is the continuous chain on which the individuals of the race are strung (Fig. 48). All acquired characters—that is to say, all characters which the Lamarckian theory supposes to be accumulated in evolution—are somatic; they affect the soma. But how is a change in the soma to alter the germ-plasm? And even if it did, how is it to alter it in such a way that when the new soma of the offspring is produced, it shall show a change of the same sort? As Weismann, the well-known German zoologist of the late nineteenth century, put it, we might equally well suppose that a message sent off by telegram in Paris would arrive in

Pekin already automatically translated into the Chinese language.

Taking it all in all, it seems probable that Lamarckian evolution, or the inheritance of any sort of acquired character, has played at most a minor and insignificant part in the actual evolution of animals and plants.

That this is so is lucky for humanity. For, it is undoubted, and even obvious, that most human beings fall far short of reaching the standard either of body or of mind to which their inherent constitution could

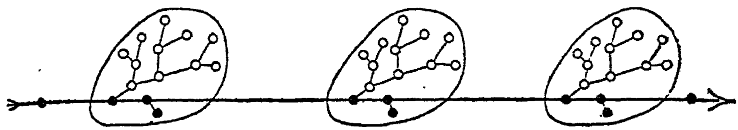


FIG. 48. Diagram to illustrate the relation between body (soma) and germ-plasm in successive generations. Only the germ-plasm, represented by a succession of dividing germ cells, is continuous from one generation to the next (black line with arrow). Single individuals are represented by ovals, containing somatic cells (white circles), all of which die, and germ cells (black circles), some of which produce the next generation. The son is therefore not descended from his father's body (soma), but both father's soma and son are descended from a common ancestor in the shape of the fertilized egg which grew into the father.

develop if it was made the best of. Either through their own fault, or through the fault of a bad environment, in the shape of poverty, slums, monotonous life, unhealthy work, or unhappy family circumstances, they are in some way or another under-developed. If this under-development were inheritable, the majority of the race would be undergoing a steady degeneration. As it is, however, a good stock in a bad environment continues to produce potentially normal and healthy children, that only want good surroundings to unfold their possibilities.

The second great theory of the method of evolution is that of Natural Selection.

Darwin himself saw it forced upon him as the necessary consequence of the following facts of biology:—

1. The fact of heredity. All organisms tend to resemble their parents.

2. The fact of variation. No two organisms are exactly alike. Thus

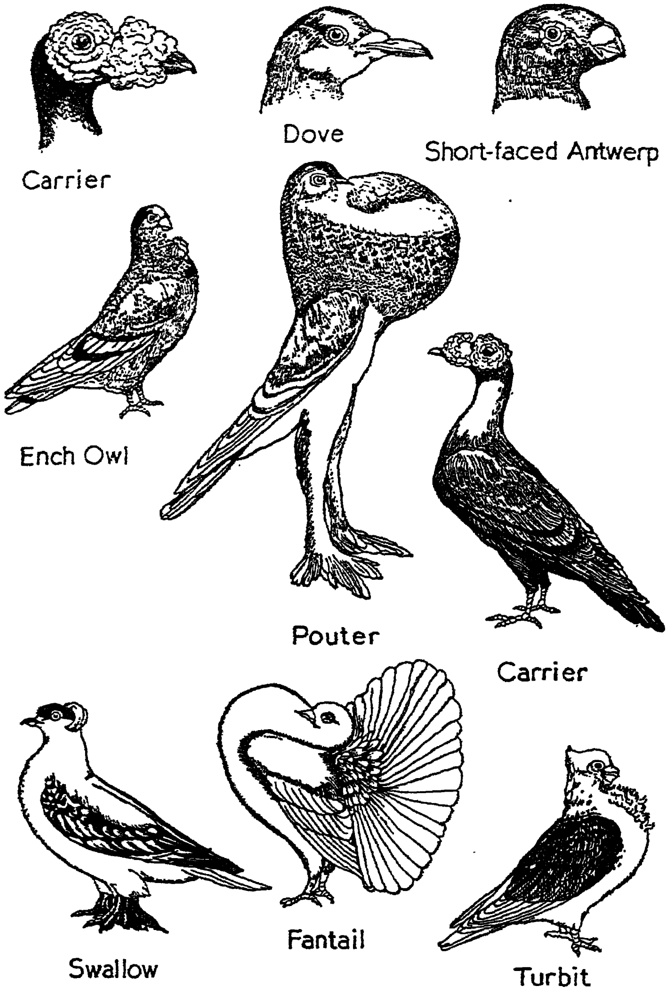


FIG. 49. Nine varieties of domestic pigeon, to show the remarkable variations of shape, proportions, colour, number of feathers in the tail, etc., which have been produced by selection from the single original stock of the wild Rock Dove (*Columba livia*).

the resemblance between parent and offspring is not absolute. Further, some variations at least are inheritable.

3. All organisms produce more offspring than can survive. If all, or even half the young, even of the slowest-breeding known animal, the elephant, were to come to maturity and themselves reproduce, the whole globe would in a limited time become packed with elephants.* While what would happen if all the million or two eggs of every sea urchin came to maturity baffles imagination! Thus, among the individuals of every species, there is of necessity a *struggle for existence*—not necessarily a conscious struggle, but none the less a real competition in effect.

The conclusion to be drawn is this—that those individuals which possess variations helping them in the struggle will on the whole survive, while those which have varied in the opposite direction will on the whole be killed off. Those that survive will reproduce the race, and by the operation of heredity, their offspring will tend to resemble them—in other words, will tend to possess the same favourable variations. This process Darwin called *Natural Selection.*

Natural Selection may thus be compared to a sifting of the individuals of a race, a sifting which results in the race coming to consist only of such individuals as are best *adapted to their environment.*

Darwin clinched his argument by pointing to the effects of artificial selection. Look, he said in effect, at the different breed of dogs, of pigeons (Fig. 49), of horses, the different kinds of vegetables, corn or fruit. A Shetland pony, a race-horse, and a cart-horse, exhibit much greater points of difference than do many natural species. If a zoologist who by some accident had never seen a dog were shown a greyhound, a pug, a mastiff, and a dachshund, he would probably classify them in different genera. Yet they, as well as the types of horses and all the other breeds of domestic animals, have been produced by selection, the breeder keeping such animals as came nearest his ideal, rejecting the others and not allowing them to reproduce. If artificial selection can produce such results in the short period covered by history of man, Natural Selection, argued Darwin, in the vast periods of

* Darwin calculated that each pair of elephants normally produced about six young during its breeding period, from thirty to ninety years old. If this rate of reproduction continued, then in 500 years a single pair would have fifteen million living descendants. The problem is, of course, one in simple geometrical progression.

geological time could produce all the diversities seen in the animal and plant kingdoms.

Another form of selection, which as Darwin saw, must operate among the higher forms of animals, is that which is called sexual selection. Just as natural selection is the immediate outcome of the struggle for existence, so sexual selection is the result of the struggle for reproduction. Where, as in all higher animals, reproduction is sexual, any advantage in finding a mate will give an evolutionary advantage, since the more successful animal will leave more descendants, who will on the average inherit the same qualities which ensured

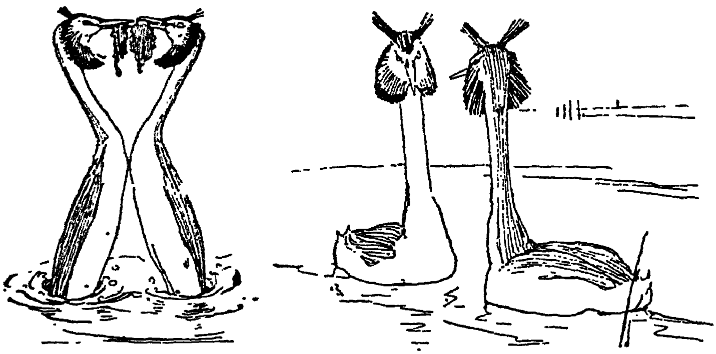


FIG. 50. "Mutual courtship," as illustrated by the crested grebe (*Podiceps cristatus*). In the breeding season, both male and female develop the chestnut and black crests and black "ear tufts." These are absent in winter. Right, the commonest form of display, in which the birds, with erected necks and partly spread ruffs, shake their heads repeatedly at each other. Left, a display less frequently seen, in which the birds, after diving and fetching nest material (water weed) from the bottom, swim at each other, and leap up to meet each other breast to breast, with fully spread ruffs.

their parent's success. Thus, while in Natural Selection the sifting mechanism consists almost exclusively of the inorganic environment together with the actions of the animal's organic competitors, in sexual selection it consists largely of the mind of the opposite sex of the same species. In other cases, however, the males fight for the females, and here strength, skill, vigour and protective and offensive weapons will be the decisive factors. Characters originating in this way are illustrated by the antlers of deer, the canine teeth of horses,

the spurs of male game birds, the mane of the lion, or the enormous size of the males in many seals.

However, the more interesting qualities developed by sexual selection are those which have had to go through the sieve of the mate's mind. As we should expect, the characters most encouraged by this means will be those which most readily please, stimulate, or excite the mind, especially on its emotional side. And, as a matter of fact, they are just such characters: brilliant colours like those of male pheasants, often combined with striking patterns and structures, as in the train of the peacock; wonderful ceremonies or dances such as that of the grebe (Fig. 50) or the Argus pheasant (Plate 16), in which bright or beautiful plumes are shown off in a startling or unusual way; or again, pleasant scents, such as those emitted from special scales by male "blue" butterflies, or actually sprayed over the female by the male, as in the African butterfly *Amauris*; or gifts of food, as are made by some spiders and insects; or the instinct to construct regular "art galleries" such as are made by the bowerbirds of Australia; or love songs, like those of grasshoppers or song birds; or even special vibrations, like those indulged in by numerous males among the web-spinning spiders (a very necessary precaution, since if they did not vibrate the female's web in a special way, different from that produced by the struggles of captured prey, the female would in all probability kill her suitor before realizing her mistake).

One thing is interesting. On the whole, the characters that have been evolved through sexual selection are either pleasing or interesting to us, showing that in general wherever there is a mind at work, it is pleased and stimulated by the same kinds of things that please and stimulate our minds. Often, it is true, the details of the display character seem grotesque or even unpleasant to us, but this is generally due to some incongruousness.

Characters like these are usually developed only in the males, the selection being exercised by the mind of the females. In such cases, selection will be most effective where polygamy prevails, as in blackgame, since there the favoured male may leave a very large number of young, the unsuccessful males leaving none at all. In other cases, however, notably in birds in which both sexes share the duties of sitting on the eggs and looking after the young, and there is thus a

real family life, the stimulation and the selection is mutual, and adornments are evolved in both sexes. In such cases, the ceremonies and dances connected with display appear to have taken on an additional function, namely, of providing an "emotional bond" which helps to keep the family together for the good of the species.

In any case, the evolution of sex, the final ousting of all other forms of reproduction by sexual reproduction, followed by the development of brain and mind to a high level at which emotions count in determining behaviour, made the operation of sexual selection inevitable; and this in its turn determined the evolution of a very great deal of the beauty and interest of the higher forms of life.

Lamarckism in the broad sense implies a direct action of the environment upon the constitution of the race. The Selection Theory, it will be seen, only demands an indirect influence of the environment, but in both cases the environment plays a great part in guiding the direction of evolution.

A third theory of evolution has been advanced, called Orthogenesis, or development in straight lines. In its strict sense, this view implies that evolution proceeds in any particular direction, not because of any advantage gained by the race, nor because of any direct moulding effect of the surroundings, but because of some inner urge, some necessity for the hereditary constitution to change in just that particular way. However, many of the points adduced in favour of the theory turn out not to support one theory of the method of evolution more than another, but to be merely statements of fact—of the very interesting fact that evolution *does* often (as in the horses, for instance) pursue a slow and straight-line course. In these cases, the theory of Natural Selection will serve equally well to account for the facts, without our having recourse to any new principle. On the other hand, some very puzzling cases are known. For instance, the great group of ammonites, a division of molluscs related to the cuttlefish and nautilus, and now all extinct, were very abundant in the secondary period. Many of them, towards the close of their hey-day, not only evolved along straight lines, but along lines which seem to be dooming the evolving race to eventual extinction. It is difficult to account for this in terms of either Lamarckism or of Natural Selection. It is clear that the range of possible variations is limited by the particular hereditary

constitution: no insect can, it appears, ever develop bone, no vertebrate can produce a compound eye. This implies a limited form of Orthogenesis; and perhaps in certain cases the restrictions imposed by the nature of the constitution are greater. In any case, Orthogenesis can never be more than a subsidiary method of evolution.

Since Darwin's time, knowledge has increased in many ways, and has compelled us to revise or re-state some of his conclusions. For instance, we now know much more about heredity, about the way in which organisms tend to resemble their parents (pp. 156 *seq.*). We also know much more about variation.

Some variations turn out not to be inheritable at all. We have already considered some under the head of acquired characters; and, as a matter of fact, a great many, perhaps the majority of the minute differences which distinguish individuals are of this sort. In general, these non-heritable variations are called *modifications*. Opposed to them are variations which can be inherited. These are called *mutations*. They may be very striking, as in the case of the Ancon breed of sheep mentioned by Darwin, where a single unusual ram suddenly appeared in a strain of ordinary sheep. This ram had short crooked legs and a long back like a turnspit dog. It transmitted its characters to its offspring, and from it a whole new breed of sheep was produced, the value of the breed being that owing to its inherited peculiarities it could not jump over fences. Or mutations may be so small that they are masked by the effect of modifications and are only to be detected by special experiments. A good example is given by the weights of bean seeds, a problem worked out by the Danish botanist Johannsen.

If a number of bean plants are grown and their seeds weighed, the weights will range widely—from about 200 to 900 milligrams in this particular experiment. The seeds of any single plant, however, will have a much narrower range of weight. Further, the ranges of weight for the seeds of different plants may overlap, e.g., those of one ranging from 200 to 650, of another from 400 to 900 milligrams. If the seeds of one particular plant are saved, and grown separately, they will produce plants each of which will have the same range of seed weight as did its parent.* This range of weight will be the same whether the

* Beans reproduce by self-fertilization. This process continued for a number of generations results in the organism being pure (homozygous) for all the Mendelian factors it carries. Such a homozygous stock is known as a *pure line*. All beans, therefore, unless artificially crossed, belong to pure lines.

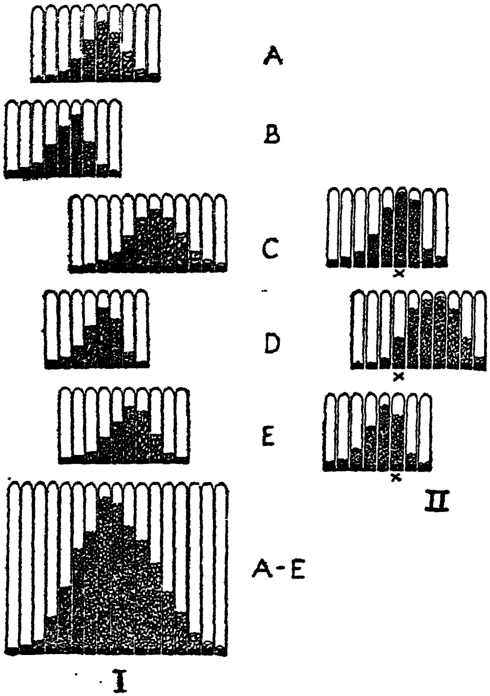


FIG. 51. I (A to E), five pure lines of beans. All beans of a given size are put in a single tube; tubes containing beans of the same size are vertically over each other. Pure line C had the largest average size of bean, B the smallest. Below (A–E), the result of mixing the five samples A, B, C, D, E. II, mutation in a pure line. Above, the range of bean-size (frequency curve) from one particular pure line. Below, two new strains, of different average size, which arose suddenly from it on different occasions and bred true.

bean which gave rise to the plant was light, medium or heavy. Conversely, however, two beans of the same weight, which have come from two plants with different ranges of seed weight, will produce plants giving different ranges of seed weight in their turn. It is clear that there are in existence a number of hereditary variations or muta-

tions affecting seed weight. Plants possessing one of these will have seeds not of a definite and constant weight, but varying again (this time by modification) between fixed limits. The amount of the modification, however, does not affect the hereditary constitution, and the range of weight remains constant from generation to generation. The average weight for each strain (under given conditions) is fixed by heredity; but the differences in weight within the beans of one strain are due to environment—to the plant being in better or poorer soils, to the bean being at the base or the tip of the pod, the pod at the base or the tip of an upper or a lower branch, and so on (Fig. 51).

If selection for weight of seed were to be made among a large mixed lot of beans, and only those plants which had beans above a certain weight were used for breeding, we should get a rapid increase of average seed weight in the population. This would be because all the strains with low average weight, not being allowed to reproduce, would be eliminated altogether. After a few generations, however, selection would no longer produce any effect upon the average weight. The reason of this would be that we were now dealing only with the strain with highest average weight, all the rest having been selected out; and each single strain breeds true to its average whether we select its heaviest or its lightest beans from which to breed. Further progress could only be made if a new mutation were to crop up (as might quite possibly happen, and as did happen during one of Johannsen's experiments) in the direction of greater seed weight.

Recent breeding experiments have shown that new mutations are continually cropping up in all sorts of animals and plants, both wild and domesticated. For instance, in a species of the little fruit-fly Drosophila, the American zoologist Morgan has discovered over 400 new mutations, all of which have started from pedigree stock in the laboratory and all of which are inheritable. Some of these involve very small changes only, such as a slight difference in eye colour, while others, such as a mutation which makes the flies almost wingless and incapable of flight, are far reaching in their effects. Any one mutation may, it appears, influence any structure or function of the body in any direction.

Darwin's statement concerning variation must therefore be put in a new form. It should run thus.—All animals vary continually and in

every part. A great deal of this variation is due to modification resulting from differences in environment, and is not inherited. Inheritable mutations, however, also occur which affect every part. In any given species a great number of these mutations are already in existence, and new ones are regularly arising.

Natural Selection, therefore, is a selection of mutations, large or small. At present we know very little as to *why* or *how* mutations originate. That is one of the greatest tasks before biology in the immediate future. But the fact that they *do* originate is sufficient to make evolution by Natural Selection possible and intelligible.*

In this way, by the constant killing-off of more organisms with disadvantageous mutations, and the survival of more organisms with advantageous mutations, change will occur in the direction of better adaptation.

It must never be forgotten that a very slight advantage will in the course of generations come to preponderate. If for example, at the beginning of a glacial epoch, when the climate were growing slowly colder, a mutation occurred in a particular kind of beetle such that it gave a 1 per cent advantage to its possessor—in other words that on the average 100 individuals with the new character survived, but only ninety-nine without it; suppose further that the new mutation and the old condition were simple Mendelian allelomorphs (p. 159); and that the new mutations were dominant; suppose further that the mutation existed in 1 per cent of the population. Then it can be calculated that after less than 500 generations, half the population will show the new character, and that in 1658 generations (not a long period in evolutionary history) 99 per cent will show it. Somewhat different but essentially similar figures will apply to recessive characters.

That selection does take place in nature is known by many observations. To take a simple instance, after a severe storm, an American naturalist collected a number of sparrows which were lying exhausted

* The matter is not quite so simple as it appears at first sight. One great difficulty is that most of the mutations found to occur in the laboratory seem to make the animal less well adapted to its surroundings and often to be definitely harmful. However, the mutations most easily detected will usually be those with large and striking effects; and a large change will be likely to throw the animal's organization out of gear. Mutations of small amount which do not throw the machinery out of gear but may even improve it, must also be occurring, but the smaller they are the more difficult will they be to detect. Very recently, it has been found possible to produce large numbers of mutations in Drosophila by X-ray treatment. This discovery should lead to a great extension of our knowledge in the near future.

on the ground. Some of these recovered, the rest died. The wings of those that recovered were nearer the average for the species; the wings of those that died were on the average either much larger or much smaller than the normal.

The theory of Natural Selection, in the slightly altered modern form that we have stated, is becoming more and more firmly supported by evidence as time goes on, and there can be now little doubt that it has been the most important agency in bringing about adaptive and progressive evolutionary changes.

CHAPTER ELEVEN

THE GENERAL PROCESSES OF EVOLUTION

As we have already seen, one of the most important properties of animals and plants is adaptation to their conditions of existence. Of this obvious but most fundamental point, it will be as well to give a few examples from widely different groups of animals. Birds and mammals both possess a constant temperature which is ordinarily well above that of their surroundings. They should, therefore, be equipped with an arrangement for preventing too rapid loss of heat; and this is provided by the feathers in one case, the hairs in the other.

Swimming birds, almost without exception, are web-footed or lobe-footed (Fig. 52). The Jacana, which seeks its food on the floating leaves of water plants, has enormous toes which distribute its weight as do skis or snow-shoes on the thin crust of snow. Indeed, in general the feet of birds are remarkably well adapted to the life which their owners lead (Fig. 52). The egg-eating snake, Dasypeltis, possesses a special mechanism by which it can temporarily dislocate its jaws to swallow an egg whole. In addition, one of its neck vertebræ bears a downwardly directed spine which protrudes into the gullet, and is used to crack the egg where none of its contents will be wasted. The larvæ of crabs live near the surface of the sea, and are provided with long spines which increase friction and make them less ready to sink (Plate 17 (i)). But the most striking examples are those known as convergence, where a similar mode of life produces similar effects on quite unrelated animals. For instance, it is advantageous for many animals to be invisible against their surroundings, either to escape their enemies or to approach their prey unobserved. And we find that in polar latitudes many animals are white, at any rate in winter, in deserts many are sandy, in undergrowth many are blotched and streaked so as to break up their outline, and harmonize with the tangle (Plates 17–19, and Figs. 53, 54).

Others, again, escape their enemies by mimicry, as it is called—by resembling other animals which are dangerous or distasteful. Thus wasps, which advertise their sting by their bright black and yellow

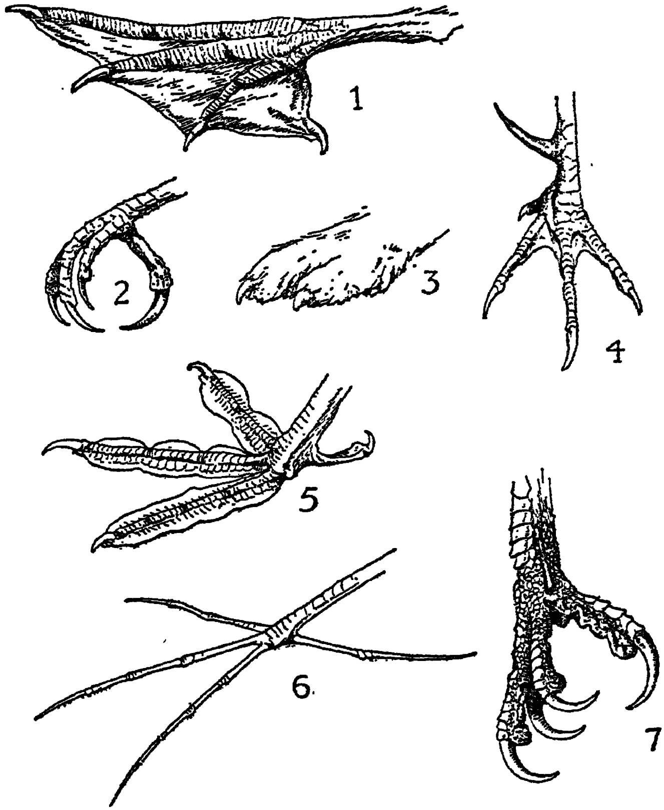


FIG. 52. Adaptation of structure to mode of life as illustrated by the feet of various birds. 1, Shag (webbed for swimming); 2, crow (perching, grasping); 3, ptarmigan (running, "stocking" of feathers for warmth); 4, wild jungle fowl (walking, scratching, spur for fighting); 5, coot (lobate for swimming); 6, jacana (toes elongated for walking on floating leaves); 7, sea eagle (raptorial for killing and holding prey).

pattern, are imitated (of course quite unconsciously) by a large number of different sorts of perfectly harmless insects both as regards pattern and body form. Ants may be mimicked by many other insects (Plates 18 (ii), 19, and Figs. 53, 54).

Another type of convergence concerns shape. Every one is familiar

with the typical fish shape—the stream lines of the body, permitting of rapid motion in water. When other vertebrates have taken to the sea, they too have evolved into a similar shape, as is seen in the Ichthyosaurs, a group of reptiles, and the whales and porpoises, a group of mammals.

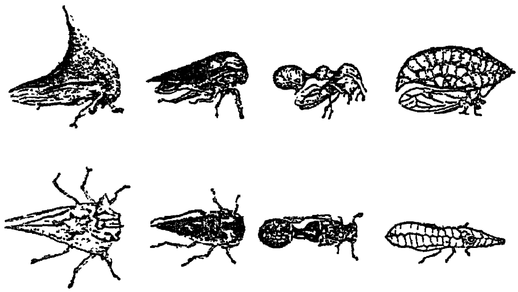


FIG. 53. Views (upper, from the side; lower, from above) of four species of plant bugs (*Membracidæ*) to show protective resemblance and mimicry. In all cases the resemblance is effected by the pronotum (upper part of the first segment of the thorax) and head. From left to right: 1, *Umbonia Spinosa*, resembling a thorn; 2, *Darnis lateralis*, resembling a grass seed; 3, *Heteronotus nigricans*, resembling an ant; 4, *Oeda inflata*, resembling in colour and shape the orange cocoon of a Syntonid moth, which belongs to a family characterized by nauseous taste. (In the view from above, the pins on which the insects are stuck are visible.) (After a photograph by A. Robinson)

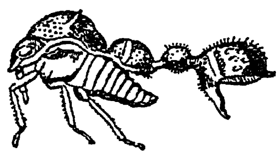


FIG. 54. Side view of a plant bug (*Membracidæ*) mimicking an ant (*see also* Fig. 53). Note the outgrowth from the dorsal side of the first segment of the thorax which gives the resemblance to the ant and covers the insect's real body completely

This adaptation of every part of an organism to its role, of every whole organism to its mode of life, is universal. It is indeed the direct and most obvious outcome of Natural Selection.

But there is another fact, of perhaps greater importance, which must be taken into account, and that is the existence of higher and

lower types of organisms. Within a few square yards we may have the man in a house, the dog in the yard, the worm in a flower-bed, the fish (probably a goldfish) in a pool in the garden, and the amœba also in the pool, or in a water-butt. They are all living close together, but their effective environments are amazingly different in extent. Most of the happenings to which the amœba responds accurately take place within a radius of a millimetre or so; when stimuli like light or vibration affect it, it has no means of discovering anything about the distance or the kind of source from which they come, but responds simply to light or to vibration as such. The total range of environment which the hydra could conceive of would be a few centimetres each way. The worm is a little larger, but still without any special sense organs; it can distinguish light from darkness, but cannot see the shape or colour or distance of anything; it can tell when the earth is vibrating, but cannot in any true sense *hear*, because it cannot distinguish tones; it cannot begin to control the environment in the same sort of way as man controls it, because it is not even in contact with most of that environment, locked away from the happenings of the outer world in a windowless existence which is almost incomprehensible to us who are provided with efficient sense organs. The fish can see images, but its vision of anything outside the water is very limited owing to the water surface, which, if it is rough, prevents vision across it. In addition, it is of course confined to water, and so, in this case, to a little pool of a few feet radius. The dog can see, can hear and smell very well, and can roam over the surface of the earth. Its environment as perceived by its senses is as extensive as that perceived by man's senses; but it cannot understand it in the same way. For instance, we can be pretty sure that no dog could ever come to understand the difference in distance between a cloud, the moon, the sun, and the stars. In addition, its brain cannot make the same reasoned relations between its sense impressions as can man. Although it can and does learn, it can only learn in an unintelligent way, making associations as they come. It does not appear capable of thinking in abstract terms of cause and effect. Its environment must seem both more limited and more chaotic than the man's. The man, if he takes the trouble to be interested in the environment in which he lives, finds it a very marvellous one. He can get information, by means of a

microscope, of invisible things under his nose; he can also obtain information, by spectroscope and telescope and mathematical calculation, about the composition, size and speed of stars hundreds of light years away. He can know by letter and newspaper what others are thinking and doing, through history he can enlarge his past far beyond the limits of his single lifetime, and he can make prophecies, sometimes (like those of eclipses and comets) of perfect accuracy, concerning the future. Also he can relate the different parts of his environment to each other and to general principles. His environment is enormously greater, both in space and time, than the dog's—let alone the amœba's; and it is much more intelligible.

In addition, the six organisms are of very different sizes and degrees of complication. Amœba consists of one cell, hydra several thousand, the worm many hundreds of thousands, a man millions of millions. There are many more kinds of cells in man, dog or fish, than in hydra or even worm. As we ascend the series, we find even greater independence of external forces. Amœba and hydra are at the mercy of floods, currents, droughts. A worm is limited to a very small section of the soil. A fish is wide ranging, and can change its abode at the onset of unfavourable circumstances, but is confined to water. The dog can range on land, and, finally, man is at home in every latitude, and has mastered sea and air as well as earth.

When we look carefully into the matter, we can see that here, too, the differences between members of the series can be thought of in relation to the environment, but in a much more general way than is the case with special adaptations. Using the word environment to denote the whole series of events and processes with which life can come into contact, and not merely the particular environment of one particular organism, we can say that some animals have more control over the environment than others, and are more independent of it. The savage is more at the mercy of the elements than is civilized man; civilization is learning to control floods and droughts, to make a pathway of communication of the same sea which to the savage is an impassable barrier. The dog in its turn is not able to cultivate the ground or to kill such varied game as the savage. The fish can exert far fewer different movements than the dog, and is much less able to profit by experience. The earth-worm is not only without specialized

organs of locomotion, but also lacks all organs of special sense.

So far as independence goes, it is well to remember that amœba and hydra are bathed, over the whole of their absorptive surface, by the water in which they live, and that accordingly any changes in the composition of that water act immediately upon the vital processes of the animals. In addition, they do not possess any mechanism for regulating their temperature, and so must live slow or fast according as their surroundings are cold or hot. In man or any mammal or bird, both the temperature and the chemical composition of the fluid which is in contact with all the cells of the body are, as we have seen, kept constant with an extraordinary degree of accuracy, and special devices exist for preventing changes in the outer world from exerting their full effect upon the vital processes of the body.

In brief, we may say that high and low organisms can be distinguished by the degree of their control over and their independence of environment. This difference in independence and control is reflected in their structure and their capacity for self-regulation and, in the mental sphere, by the degree of knowledge of the outer world which their sense organs and brains permit, and in all probability by the intensity of their emotions.

From what we know about evolution it is clear that the highest organisms have developed latest in time. This we can actually see happening as we trace back the history of life in the fossils; it is a probability which amounts for all practical purposes to certainty that the converse is true, and that although the early stages of the earth's history as written in the rocks and fossils are now undecipherable, yet that the first forms in which life appeared were low organisms.

At the beginning, then, there were only low organisms, today there exist all gradations between the highest organisms and the lowest; as we shall see later, undoubtedly many organisms have degenerated during evolution from a higher to a lower condition. If we look back into the history of fossils, and investigate what forms of life were present before and after the development of some new high type, such as man or the mammals, we shall almost always find that the new type has simply been added to the previously existing types. For instance, the reptiles were the dominant land animals in the Secondary period, before the development of the higher or placental mammals;

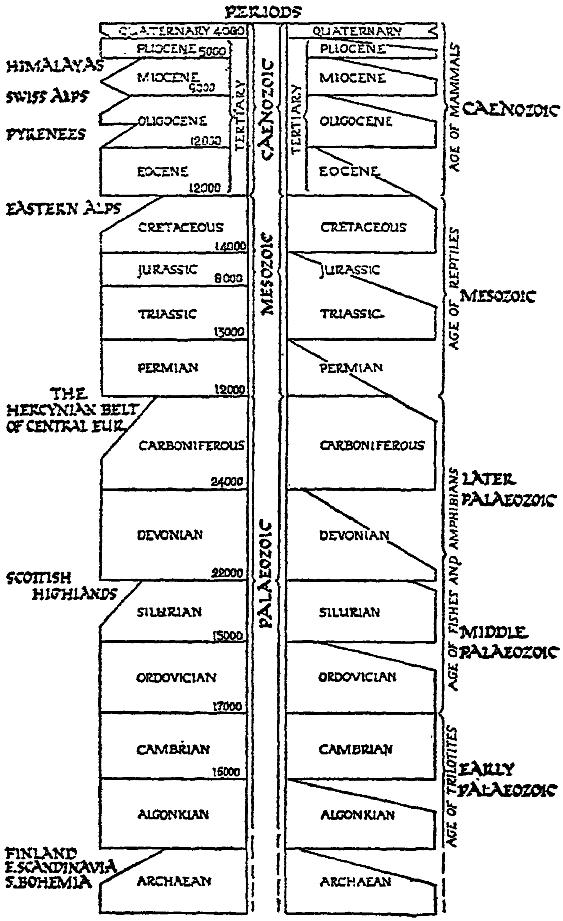


FIG. 55. Diagram of the main geological periods. The figures give, in feet, the approximate maximum thickness of the sedimentary rocks laid down in each period. The total thickness since the beginning of the Cambrian is thus about 36 miles. The incisions indicate the periods when various great mountain systems were formed—Eurasiatic on the left, American on the right. The dominant forms of animal life are indicated on the right; it will be noted that highly complex forms (Trilobites) had already been evolved in the Cambrian.

when these were evolved, just before the beginning of the tertiary period, although they speedily became dominant on land, and although many species and even whole sub-groups of reptiles were extinguished, yet the reptilian type as a whole did not perish from off the face of the earth, but continued to exist as well as the mammals. In the same way, although the advent of man sealed the death warrant of a great many species of other mammals, reduced the total number of lower mammals very considerably, and deposed them from their previous dominant position, yet lower mammals still exist in abundance, and will undoubtedly continue to do so.

Thus we cannot say that evolution consists simply in the development of higher from lower forms of life; it consists in raising the upper level of organization reached by living matter, while still permitting the lower types of organization to survive. This general direction to be found in evolution, this gradual rise in the upper level of control and independence to be observed in living things with the passage of time, may be called *evolutionary* or *biological progress*. It is obviously of great importance, and can be seen, on reflection, to be another necessary consequence of the struggle for existence.

This improvement has been brought about in two main ways, which we may call *aggregation* and *individuation*. Individuation is the improvement of the separate unit, as seen, for example, in the series Hydra—Earth-worm—Frog—Man. Aggregation is the joining together of a number of separate units to form a super-unit, as when coral polyps unite to form a colony. This is often followed by division of labour among the various units, which of course is the beginning of individuation for the super-unit, the turning of a mere aggregate into an individual (*See* Table pp. 296-7).

Let us take as an obvious example of biological progress the colonization of the land by vertebrates. As a matter of verifiable fact, the sea was already peopled with highly developed fish before the first amphibians appeared on land. In other words, while there existed great competition among vertebrates in the sea, this competition did not as yet exist on the land. Clearly, then, it would be a biological advantage to any species if it were to vary in such a way as to make it able to live on land, for then unchecked multiplication would be possible for it, and it would have fewer enemies. Variations in this

AGGREGATION

	Single cells	Colonies of cells without division of labour	Colonies of cells with division of labour	Metazoan individuals	Segmented Metazoa	Colonies of Metazoa without division of labour	Colonies of Metazoa with division of labour
Reason, speech and tradition. Habitual use of tools and fire						Ancestral Man	Modern Man
Elaboration of intelligence. Evolution of hands, increased reliance on sight					Higher Primates	Gregarious Primates	
Elaboration of associative memory. Warm blood, increased pre- and post-natal care					Birds, Mammals, Higher Reptiles	Gregarious Birds, Mammals, and Reptiles	
Elaboration of instincts					Highest Insects, e.g., solitary bees, wasps; Spiders	} Colonial Insects	Social Insects, (ants, social bees and wasps termites)
Terrestrial life fully adopted					Many Insects and Arachnids, Reptiles		
Terrestrial life, but confined to moist places, often breeding in water				Land Molluscs (snails and slugs)	Amphibians, Land Crustacea		
Further elaboration of brain and head				Many Molluscs (whelks, sea slugs, etc.)	Fish, higher Crustacea, Lampreys	Gregarious Fish	
Elaboration of locomotor and sense organs, primitive head				Primitive Molluscs (Chiton)	Lower Arthropods (water-fleas, etc.)		
Cœlom, elaboration of heart, gills and feeding mechanism				Echinoderms, solitary Polyzoa, Bivalve Molluscs, Lampshells	Earth-worms, Leeches, marine Annelids, Amphioxus, Simple Ascidi-	Compound Ascidians, colonial Polyzoa	Salps and other colonial pelagic Tunicates
Blood-system				Nemertine worms			
Anus				Rotifers, Nematode worms			
Three layers, central nervous system, excretory system				Liver-fluke, free-living Flat-worms	Tapeworms		
Nerve-ring				Jelly-fish			Siphonophora (Portuguese man-o'-war, etc.)
Mouth, nerve-net				Hydra, sea anemones		Various Corals, etc.	Many colonial hydroids
Two layers				Simple Sponges		Bath sponge and other colonial sponges	
Elaboration of cell organs	Complex Protozoa, higher Ciliates	Colonial Vorticellids, e.g., Carchesium	Colonial Vorticellids, e.g., Zoothamnium				
Nucleus	Simple Protozoa, Amoeba, etc.	Pandorina	Volvox				
No formed nucleus	Bacteria	Colonial bacteria					

FIG. 56. Table to illustrate the share of the processes of aggregation and individuation in progressive evolution. Aggregation consists in the biological union of a number of separate organic units. The union may be physical, as in colonial hydroids, or effected through sense organs and behaviour, as in gregarious mammals or insects. Individuation consists in the specialization and division of labour of parts within the whole. The parts specialized may be the units employed in aggregation, or other parts, of smaller or larger magnitude. Metameric segmentation is treated as a partial form of aggregation (multiplication of one body-region).

direction would thus tend to be preserved; in other words, this particular step in biological progress would be favoured.

As a matter of fact the step is a very large one, and progress was inevitably slow. The Amphibia did not arrive at a complete solution of the problem of leading a terrestrial existence. Their skin is moist, they are usually confined to wet places even in their adult existence, and the earlier part of their life is almost invariably spent actually in water, in the shape of a tadpole larva.

With the evolution of the Amphibia the fringe of the dry land, the territory between land and water, had been conquered, but not the dry land as a whole. Once again, after millions of years during which the Amphibia were the highest vertebrate type, evolving life was confronted with a situation in which a premium was placed upon a further advance: animals born with heritable variations making it possible for them to live farther and more permanently away from water would become heirs of a rich unoccupied territory. Thus it was that the Amphibia, after themselves arising from the fish, in their turn gave origin to the reptiles.

In the same way, in the continual struggle that is going on in mammals or birds between herbivore and carnivore, pursuer and pursued, each new advance in speed and size or strength in one party to the conflict, must call forth a corresponding advance in the other, if it is not to go under in the struggle and become extinct. The striking improvement in the running powers of the horse family during its evolution, evinced in increase of size, lengthening of the legs, reduction in the number of the digits, and development of a well-formed hoof (*see* Fig. 57), and the similar improvements that occurred in other Ungulates, were accompanied by a corresponding increase in the size, speed and power of the group of Carnivora during the same geological periods. Each was at the same time the cause and the effect of the other.

A precisely similar state of affairs is often to be seen in the evolution of the tools and weapons and machines of man. For instance, in naval history, the increase throughout the nineteenth century of the range and piercing power of projectiles on the one hand, of the thickness and resistance of armour plate on the other, provides a very exact parallel with the simultaneous increase of speed and strength in both

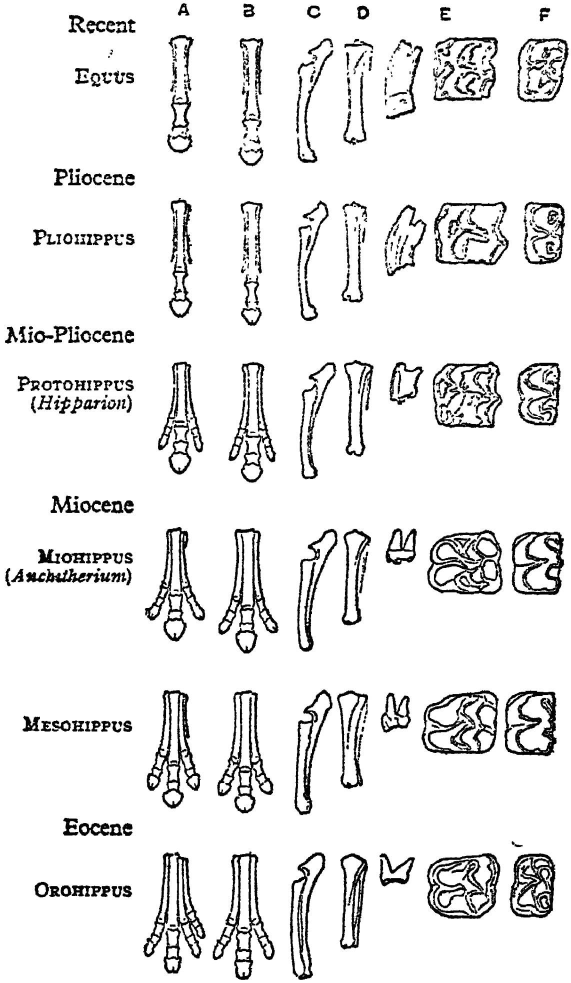


FIG. 57. To illustrate the evolution of the horse, from the Eocene period till today. The earliest types are placed below. The number of digits on both limbs is slowly reduced; the middle digit is enlarged and specialized as a hoof; the fore-arm is strengthened by the fusion of radius and ulna, the ulna in its distal part disappearing; the hind-limb is strengthened by the disappearance of the fibula and corresponding enlargement of the tibia; the length of the tooth is increased; its grinding surface becomes more complex. In addition (Plate 1 (ii)) there is an increase of size and change of proportions.

carnivores and their prey. In Nelson's time, the men-of-war were built of unsheathed wood, and the guns fired round iron balls, with a maximum range of a few hundred yards. Today, battleships carry 15-inch guns which fling steel-capped and pointed projectiles, laden with high explosive, for a dozen miles or so, while the armour plating of heavily protected ships may now reach a thickness of a foot or even more of specially treated nickel steel.

During the interval, progress has been steady and gradual in both departments of naval warfare, each advance in efficiency of guns being the stimulus for new invention in the methods of protection, and vice versa.

It is when there is a general increase of the animal's powers of control that we speak of progress; when the increase is in one special particular only, we speak of specialization. For instance, the horse is specialized for running, the mole for burrowing, the bat for flying, the whale for a marine life, the lion for catching and devouring large animals, the sloth for living in trees. Each of these animals is well adapted for its particular mode of life, but each is by that very adaptation quite cut off from leading the life of any other. During the late Secondary period there existed similarly specialized types of animals. For example, the Ostrich Dinosaur was adapted for running, the Ichthyosaur for life in the sea, the Tyrannosaur for preying on large animals, the Pterodactyl for flight, and so on. But all the former list of animals are mammals, all the latter were reptiles. The mammals are higher in that they possess proper temperature regulation, for instance, and better pre-natal care of their young, as well as in many other points. Thus, while the types of specialization, or of adaptation to particular modes of life, are somewhat similar in the two cases, yet each member of the first group is higher than any member of the second, because its general organization is on a more efficient level.

Whenever a new group of animals is evolved, it is found that its members soon become specialized in different directions, thus filling up different vacant places in the economy of Nature. This adaptation to different modes of life, while, as we have seen, we call it *specialization* when we are thinking only of one species of animal, is called *adaptive radiation* when we are thinking of the group as a whole. All fish, for instance, breathe by gills, possess fins as limbs, and have other

FIG. 58. To illustrate adaptive radiation in the reptiles. (1) Primitive type (Pareiosaurian). (2) Sphenodon, the primitive New Zealand reptile. (3) Mammal-like type (Theromorph). (4) Lizard with vestigial limbs (Skink). (5) Snake. (6) Chelonian (Elephant Tortoise). (7) Crocodile. 8–11, Dinosaurs: (8) Ceratosaurus (carnivorous); (9) Diplodocus (herbivorous, gigantic and semi-aquatic); (10) Triceratops (herbivorous, with defensive horns and bony head-frill); (11) Iguanodon (herbivorous). 12–14, Marine types: (12) a Pythonomorph; (13) an Ichthyosaur; (14) a Plesiosaur. (15) Aerial type, Pterodactyl. All except 2, 4, 5, 6 and 7 are now extinct.

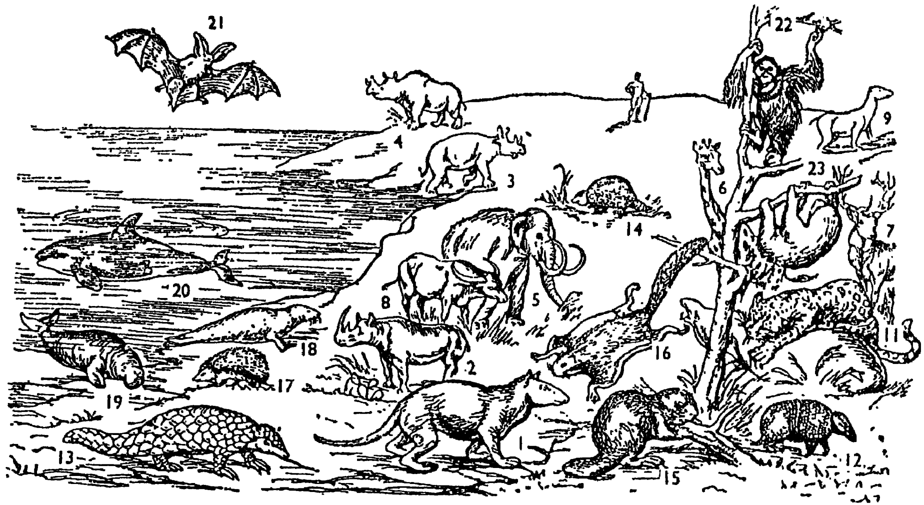


FIG. 59. To illustrate adaptive radiation in the placental mammals. (1) Eocene mammal of generalized type (Condylarthran). 2–8, Herbivorous forms with defensive horns or other weapons: (2) Rhinoceros; (3) Amblypod; (4) Titanothere; (5) Mammoth; (6) Giraffe; (7) Red Deer; (8) Buffalo. (9) Extinct South American Litopternan (herbivorous). (11) Carnivorous type (Jaguar), preying on herbivorous Tapir. 12–14 and 23, Edentates: (12) Armadillo; (13) Scaly Anteater; (14) Glyptodont; (23) Sloth (arboreal). 15 and 16, Rodents: (15) Beaver; (16) Flying Squirrel. (17) An Insectivore (Hedgehog). 18–20, Marine forms: (18) a marine Carnivore (Seal); (19) a herbivorous Sirenian (Dugong); (20) a Cetacean (Killer Whale). (21) An aerial form (Bat). (22) A Primate (Orang Outang). Primitive man in background. 1, 3, 4, 9 and 14 are extinct types. 5 is extinct, but the elephant type survives.

characteristics in common, so that any member of the group can be at once recognized by a brief examination of its structure. Yet the detailed form of different species of fish is extremely varied. Besides the ordinary type of active, free-swimming fish, like the herring or trout or mackerel, there are fish flattened in adaptation to life on the bottom, some flattened sideways, like the sole and plaice, others flattened from above downwards, like the skates and rays; there are elongated fish like eels and pipe-fish; there are fish with prehensile tails, like the sea-horse; there are the flying-fish adapted for leaping long distances out of the water; mottled fish of irregular outline adapted for living on rocks; deep-sea fish with wonderful phosphorescent organs for searchlights and huge eyes for perceiving the faintest trace of light; cave-fish without eyes at all; sucker-fish adapted for sticking tight to the underside of stones, or for being carried about by larger fish without expending any energy themselves; and so on and so forth through almost every conceivable sort of form possible in an under-water existence.

The examples previously mentioned give an idea of some of the adaptive radiation which has taken place in reptiles and in mammals; very similar instances could be taken from any other large group, such, for instance, as the insects. It is interesting to take any such group and to see what part adaptive radiation has played in giving rise to the main sub-groups into which it is divided (Figs. 58, 59).

There is one particular form of specialization which we have not so far mentioned; and that is the retrograde form of specialization known as degeneration. There are many cases known where animals can be definitely shown to be less highly organized today than were their ancestors in the past. The animal known as Sacculina, for instance, is a parasite upon various sorts of crabs. It consists of a mere bag filled with little else but reproductive cells, and sending out a whole series of branched roots which penetrate the crab's body in all directions and suck nourishment out of it. At first sight, the relationships of this unpleasant creature are very difficult to determine. But when its development is investigated, it is found that it hatches out of the egg as a free-swimming larva exactly like those found in many Crustacea. It has jointed limbs, an external skeleton made of chitin, and in fact bears all the distinguishing marks that other Crustacea do, be they

crabs or lobsters or shrimps or water fleas. It is, in fact, a crustacean which has become adapted to a parasitic life; and in so doing it has acquired special adaptations, such as the root-like organs, specially suited to that life, while it has lost sense organs, limbs, digestive system, and everything else necessary for leading a free and independent existence. It has lost more than it has gained, its organization has become simpler, its independence less; in fact, it has gone down the evolutionary hill, and the direction of its history has been in most ways the opposite of the direction which characterizes biological progress (Fig. 1).

The form in which Sacculina hatches out resembles in general many crustacean larvæ; but it is particularly like the early stages of the animals known as barnacles. Every one who has been to the seaside knows what an acorn barnacle looks like—a little creature attached to rocks or piles, enclosed in a white shell, and capable of sending out of a slit in the top of the shell a regular sweep-net composed of a number of "arms"—really appendages—with which it drags minute floating particles of food in towards its mouth.

Even in the adult state a barnacle shows some resemblance to ordinary Crustacea, especially in its jointed limbs and chitinous external skeleton; the early free-swimming larva clinches the matter and gives complete proof, as in the case of Sacculina, of their crustacean nature and affinities. The very close resemblance of the larva of barnacles to that of Sacculina points to an especially close connexion between the two sorts of animals; and as a matter of fact, the two are undoubtedly descended from a common stock.

The barnacle is degenerate as well as the Sacculina, but it is not so degenerate. It still, for instance, possesses organs for capturing and digesting food. On the other hand, it has lost its organs of special sense and of locomotion. Further, it is not adapted to the same general mode of life as is Sacculina; it is not parasitic, but sedentary or sessile. This settling down and becoming fixed is the other great cause, besides parasitism, of degeneration in animals; as would be expected, the degeneration due to a sedentary life is rarely so great as that due to parasitism, since the sedentary animal does not obtain its food ready digested as do most parasites.

It must not be supposed that because the general rule among animals

is that time brings change, that therefore time *invariably* brings change. The common lamp-shell Lingula, for instance, has persisted without any appreciable change whatever in the structure of its shell for the prodigious period of time, certainly over five hundred million years, which has elapsed since the Cambrian epoch in the Primary period. Even when individual species have changed, the general characters of groups have often persisted with very little modification, as, for instance, those of dragon flies since the coal-measures, of shark-like fish since the Silurian.

In some cases this may mean that for some unknown reason the species or the group has lost the power of varying to any considerable extent. More often, probably, it so admirably fills one particular niche in the order of things, and a niche which stays the same throughout the geological periods, that it pays for the animal or the group of animals to stay as they are, leaving it to other groups or to other branches of the same group to colonize new niches and to progress towards fuller existence.

To sum up, we may say that two main types of evolutionary change result in animals (and also, as a matter of fact, in plants) from the struggle for existence and the constant appearance of inheritable variations. In the first place, once a new type or plan of structure has been evolved, it undergoes adaptive radiation; in other words, there are developed a number of separate species all built on the same general ground plan, but adapted to different and usually incompatible modes of life. In the second place, new types and new plans are continually appearing as time goes on, and progress is marked by the fact that among the later-evolved types there is to be found greater complexity of organization, greater control and independence of environment, than among the earlier.

It might perhaps be thought that specialization was often the same thing as progress. Specialization, however, implies close adaptation to one particular mode of life, while progress means greater general efficiency. If we look into the actual history of animals in the past, we find that specialization in one direction involves the sacrifice of possible advance in other directions, and is a barrier in the long run to any but a quite limited degree of progress. As a result of its long course of specialization, extending for tens of millions of years

through the better part of the Tertiary epoch, a specialization all tending towards greater efficiency in running and browsing, the horse stock has, it seems, cut itself off from the possibility of adapting itself to other modes of life—to a life in the water or in the trees, or to a carnivorous habit. There is a limit to the perfection which any line of specialization can attain. While the horse was growing larger, developing hoofs, reducing the number of its digits, another and wholly different type was being evolved in the person of man. If it were not that horses are useful to man, and are accordingly domesticated, they would now be wholly or almost wholly extinct. The "natural" enemies of the horse are the large carnivores. These are built on the same general plan as the horse—the mammalian—and indeed are the results of the specialization of the same plan in another direction. The same limits are thus set to them as to the horse stock. Before the advent of man, a state of equilibrium existed between the horse and its enemies, the latter not able to destroy the former entirely, the first not able to escape the payment of some toll to the second.

But the horse came up against the wholly new biological conditions introduced by the new type, man; it was in direct conflict with man's cunning and tools and his habit of hunting in bands; still more important, it had to compete with the indirect effects of the new development, such as the settlement and cultivation and enclosure of the land. Against all this the horse was powerless. It could not develop far enough or fast enough to adapt itself to such sudden changes, and as a result it is becoming extinct as a wild species.

Over and over again the same thing happens, and the specialized representative of the old type, plant or animal, is extinguished in competition with the specialized representative of the new. For tree-like representatives of the horse-tail type, which existed in the Carboniferous period, we have seed-bearing trees today; for pterodactyls, birds and bats; for dinosaurs, the large mammals; for the large early amphibians, the Stegocephalia, we have crocodiles; for the abundance, both in numbers and in species, of the larger mammals in the Pliocene, we have the multifarious activities of the swarms of man.

The new type seems always to have arisen from some comparatively unspecialized branch of the old, and to have attained its pre-

eminence by means of adaptations towards general instead of towards special efficiency. Man has ousted the other mammals from their dominant position owing to the development of his mind. Through his particular type of mind he is able to deal rationally with the problems that confront him; tools, machines, tradition, civilization, and unexampled control and independence have been the result. The human mind is not merely adapted for solving one or two particular problems; it represents a *method* more efficient than any previously adopted for dealing with any and every problem that may confront an organism.

Man's body is not highly specialized, and he seems to have arisen, through a monkey-like ancestor, from some unspecialized early mammalian stock like the Insectivores. Nor did the early mammals show any signs of specialization. All the fossil mammals that we know of during the time when the great period of reptilian dominance and specialization lasted were small, primitive creatures, at first sight not likely to wrest the palm from their powerful rivals.

Very similar chains of events may be seen taking place in the evolution of human machines and inventions. Take, for example, the history of transport. The most primitive method was the carrying of single loads by human beings or pack-animals. After that came the invention of vehicles in general and of wheeled vehicles in particular. The wheeled vehicle became specialized ("adaptive radiation") in innumerable ways. We have the war chariot; the rapid vehicle for passenger transport and for pleasure; the heavy wagon and cart; the van and pantechnicon; the four-in-hand mail coaches bowling daily at fixed hours along the main roads of the land. A limit was set to the capacity and the speed of such vehicles by the speed and strength of beasts of burden on the one hand, and by the imperfections of road surface on the other.

At the beginning of last century a new type of vehicle was evolved for which these limitations no longer existed. It was discovered how to replace the energy of animals by that of steam, and in large part to overcome the difficulties of surface friction by making the wheels of the vehicles run on metal rails. As a result, steam locomotives became for certain purposes the "dominant type" of vehicle within an extremely short period of time.

Here again the type itself has been improved, so that we have now for some time been close to the limit of its possibilities. It does not seem possible to run a profitable service at speeds of much over sixty miles an hour.

About half a century later a new plan was evolved. The internal combustion engine was produced, and gave certain great advantages, notably in being ready to start at once without the long preparation of "getting steam up." It appears to be the fate of new types to lead a precarious existence for a considerable time before they can compete successfully with the dominant types of the period. This was so, as we saw, with the earliest mammals; it was so for the steam engine; and it was so, to a very marked degree, for the internal combustion engines. They were laughed at when their inventors took them out on the roads; the law laid down that they should be preceded by a man with a red flag; the early defects in construction did actually occasion many a breakdown. But within thirty years they came into their own.

Meanwhile, still another competitor is in the field—the flying machine, a totally new type, abandoning not only the particular device of the wheel, but the whole element to which the wheel was adapted. It looks as if in certain respects, where speed is the main object, the aeroplane would become the dominant type of vehicle; but that it would leave the major part of transport to be dealt with by train and by motor.

Another interesting parallel with the evolution of organisms is found in the fact that although there has been progress, although the dominant type of vehicle has altered with the passage of time, yet many representatives of the old types have survived. They have managed to survive by becoming restricted to a few special conditions and places. Pack-animals, for instance, while once universal, are now only employed in mountainous or roadless countries. The American buggy is still of the greatest use over the unmade roads which are still to be found in so many parts of the United States. The horse-drawn vehicle will long hold its own in businesses in which not much capital is available, and speed and great power are not of the first importance. This survival of all or almost all the types that arise in evolution, even though new types arise and supremacy changes

hands, is of general occurrence in the development of animals and plants, and is at first sight very puzzling. However, the insight which is gained by looking, as we have done, into the evolution of something familiar and human like the means of locomotion, helps us to understand the more complex and slower-moving processes of organic evolution.

Another point which is brought out by the study of the development of some human contrivance such as the means of transport, is the great speed of change now possible in human affairs as against the slowness of change prevailing in lower organisms. The whole period from the stage-coach to the aeroplane is comprised in well under two centuries. The resulting change in human habits has been enormous; to produce comparable changes in the habits of an animal stock there would be needed a period certainly to be reckoned in tens of thousands, possibly in millions of years.

On the other hand, the evolution of machines is a perfectly real evolution. Two different types of machines capable of performing the same general function—such, for instance, as the motor lorry and the goods steam engine—do come into a very real competition with each other, and the issue of the struggle is decided by a form of true natural selection, depending in the long run upon which of the two pays the better. Here again the study of machines throws light upon the course of events in animals. It is often supposed that evolution must involve some conscious effort on the part of the evolving organism, that the struggle for existence is a conscious struggle, or that a species in some mysterious way "learns" how to develop some new improvement in its structure.

As a matter of fact, almost the whole of such ideas are purely metaphorical, and arise simply because we read the processes of our own minds into the operations of nature; it is not scientifically correct to speak, for instance, of *purpose* except in relation to human minds. We see at once that the machines have no idea themselves of the direction of their evolution, that the "struggle" between them is only a metaphorical struggle, that the selection between them is, so far as they are concerned, a mere sifting process, the issue of which depends upon the advantages or disadvantages which they may happen to possess.

It is the same with organisms. If two races of animals come into competition, the issue is decided by the qualities which each happens to possess; "natural selection" is a name for the effect exerted by all the forces of the environment with which they come into relation, an effect which acts again like an automatic sieve, and lets some through to perpetuate themselves, keeps back and so extinguishes others. The "struggle" and the "competition" are again usually metaphorical only. For instance, when the common house sparrow was introduced into America, it entered into competition with many of the small sparrow-like birds which had developed in that country. But the struggle did not take the form of a war between the invader and the original inhabitants. It was an indirect struggle, due to the fact that both lived upon the same sort of food, both occupied the same sort of sites. The European sparrow happened to be endowed with qualities which gave it an advantage, and as a result it has spread enormously over the American continent, while many of the native birds have correspondingly decreased. If we wish to use a human metaphor, we can say that its success has been the result of "peaceful penetration," not of fighting.

The difference between machines and organisms, of course, is that the machines are directly designed by man, whereas the place of the designer in animal evolution is (roughly) taken by the variation which seems to be universal in organisms. It is variation which provides the raw differences upon which the sieve of natural selection can work. Mention must also be made of the theories of evolution which are summed up under the term *orthogenesis*, which means evolution in straight lines. It is frequently found, as for instance in the development of the horses or of the elephants, that evolution as revealed by fossils proceeds straight onward through geological time in a perfectly definite direction—in the horses towards single toes and hoofs, in the elephants towards great bulk, tusks and trunk. Orthogenesis is sometimes used merely as a descriptive term, to denote this observed fact of straight-line evolution. But by others it is used to mean that there exists some inner necessity for the evolutionary line in question to develop in just that one way and no other. However, a series of fossils, even if beautifully complete, can really give us no insight into the method by which its evolution occurred. Whenever

the direction in which the series is evolving is adaptive or seems biologically advantageous, the orthogenetic series can be perfectly well explained by natural selection. On the other hand, there do exist cases where at least no advantage can be perceived by us in the direction pursued. This is so, for instance, as regards the ammonites, the extinct cephalopod molluscs which died out near the end of the Secondary period. Near the close of their time on earth, they often evolved orthogenetically into the most bizarre forms, their spiral shell becoming unwound, or irregular. Possibly in such cases a real causal orthogenesis, an inwardly determined mode of variation, is at work. But we are justified in saying that such cases, if they occur at all, are certainly rare.

CHAPTER TWELVE

THE RESULTS OF EVOLUTION: THE ANIMAL KINGDOM

WE SEE THE thousands of different kinds of animals that exist, and are apt to become overwhelmed with the detail. Each is unique, full of interesting points; one type may be extremely different from another. It looks at first sight as if we were dealing with facts in masses too great to be properly assimilated.

But, while the facts are in a sense infinite and our understanding of them must always remain incomplete, yet we can reduce the apparent chaos to order, can get some mental grip on it as a whole, by means of a few general ideas and principles which lie ready to our hands.

For the present purpose the general principles are three, all depending upon the central idea of evolution. First, if evolution has taken place, some animals will be closer blood relations, some more distant; and by examining likenesses and differences, we can obtain a measure of the relationship. By classifying animals according to their likenesses into groups of various sizes, we can put any particular species in a labelled pigeon-hole, so to speak, where it can always be found again if it is wanted. What is more, since such groups represent collections of *related* species, our method of pigeon-holing has reality behind it, and we have a natural classification.

Working on these lines, zoologists classify the whole animal kingdom into about a dozen main groups or *Phyla*. The most familiar phylum is that of the backboned animals, to which man belongs—the vertebrates, or more accurately Chordates—while the insects belong to the group of animals with many-jointed limbs, the Arthropods; the jelly-fish to the group which possesses only one cavity to fulfil the function both of gut and body cavity, the Coelenterates; and so forth. Each phylum is subdivided into classes, the classes into orders, and so down to families, genera, and species. In this scheme every animal has two names, that of the genus coming first, and serving as a surname, that of the species following, serving as a christian name. This method of naming was invented by Linnaeus,

the great Swedish naturalist of the eighteenth century. Before his time, some animals were known only by the single familiar name like cat or pig, which led to confusion between different kinds of cats or pigs; or, in an attempt to remedy this, by a regular description (just like the long "name" of the village in Anglesea which is really a description, and has been cut down by the practical post office to a real name, Llanfair P.G.). We must give names for things before we can know what we are talking about, and Linnaeus's system of naming animals and plants was a great step forward.

In this way, then, when any species has been properly looked at and investigated, it can be put in its right place in the scheme, and if we know certain essentials about the characters of the main groups, we know a good deal about the sort of animal which the particular species is, and also about its relatives, their number and chief characteristics.

The second (as also the third) principle which will help in ordering the facts, is concerned not with the animal's blood relationships, but with its interconnexions with its environment. Animals may evolve, but their evolution must always bear a close relation to the forces around it. The result of this is *adaptation*: animals (and, of course, plants too) always show some suitability to the particular conditions in which they live. They also are fitted to the general conditions which characterize our particular planet. The planet Jupiter is so much larger than the earth that the force of gravity on its surface is about 2·64 times as much as with us. If life could exist on its surface (which at present it probably could not) this difference in the force of gravity would have necessitated various special developments. Any Jovian land animals would have to be of a very different type from those on earth; creatures like horses or deer would be physical impossibilities, and great stumpy legs would be a necessity for existence. As to aerial winged animals, they might be wholly impossible; in any case, none using any flying mechanism found among the aerial forms we know could reach more than a very small size.

Or again, no known animal has any special sense organ for detecting X-rays, or any protection from X-rays, although rays of this short wave-length are very harmful to life. Why? For the simple reason that X-rays do not exist in nature on the earth. We have not

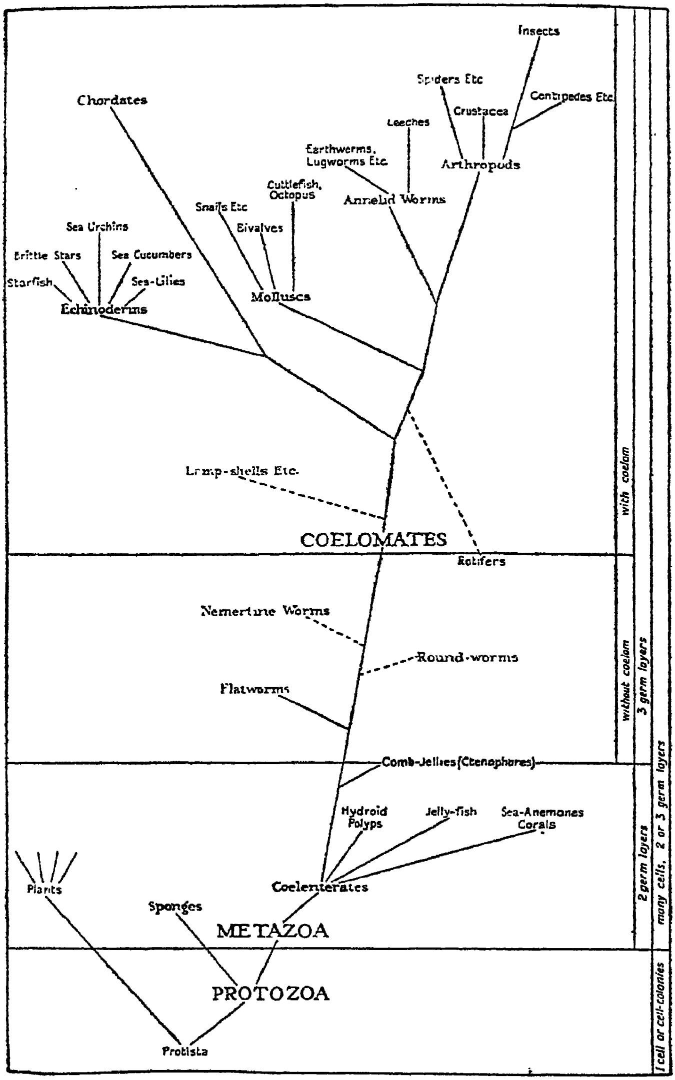


FIG. 60. A diagram of the probable relationships of the main groups of the animal kingdom. Some of the main steps in evolutionary advance are indicated at the side. A dotted line leading to a group indicates the position of the group is doubtful. Descending lines indicate evolutionary degeneration.

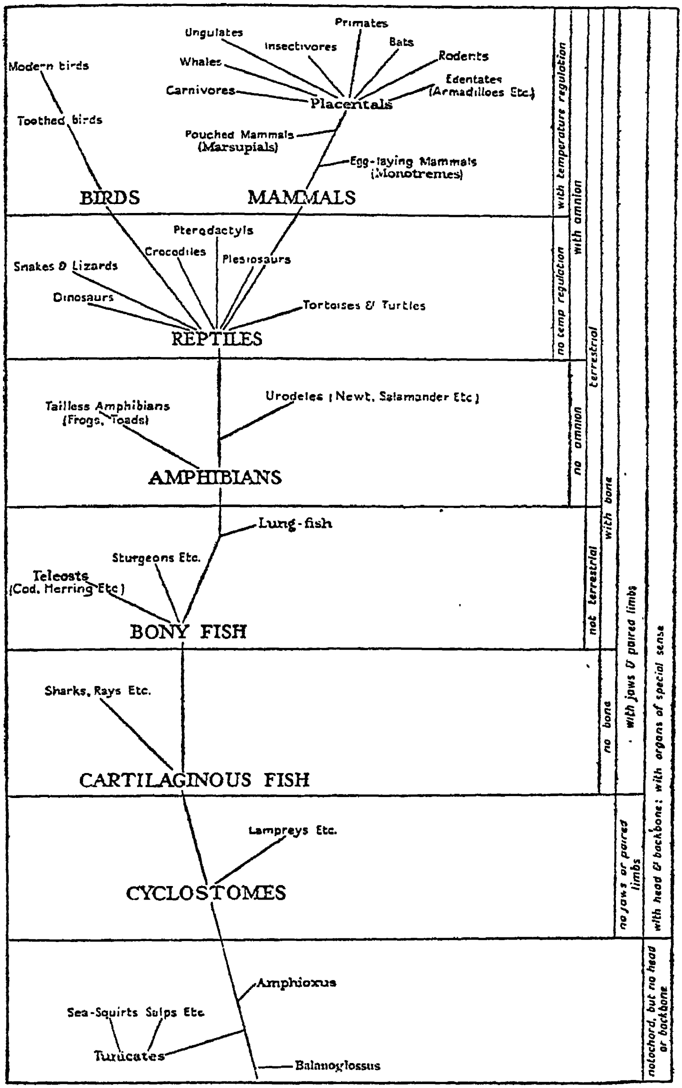


FIG. 61. A diagram of the probable relationships of the main groups of the vertebrates (*Chordata*). Some of the main steps in evolutionary advance are indicated at the side.

even any sense organs for telling a live rail or wire from one along which no electric current is passing, and many deaths occur each year in consequence. Although very big alterations of the environment are there all round the current, we cannot perceive them because in nature electric disturbances are either trivial in extent, or else occasional and uncontrollable like the lightning.

The third principle has already been touched on—*biological progress*. It is in a sense a special case of adaptation, but it is of importance since it enables us to think of higher and lower animals as well as mere relationship or special adaptation.

We suppose then that life, starting in some very simple and probably tiny form, has gradually evolved since the day when it first appeared on earth, probably between one and three thousands of millions of years. It has evolved into the huge number of species—close to a million—that are known today, as well as those, probably a far greater number, which have become extinct on the voyage through time.

The fundamental characteristics of life, its power of metabolism, assimilation and consequent growth and reproduction, are found in all creatures. Their other characters, almost without exception, are the outward and visible sign of the mode of life they need, imposed upon them by the necessities of existence.

With these main ideas in mind, we may turn to the actual animal kingdom as it exists today and in the record of fossil species, and see what we can make of it (Figs. 60, 61).

Nothing certain is known—probably nothing ever will be—about the form in which living matter originally existed on earth. It is pretty clear, however, that the units must have been small, and that one of the earliest types of organization evolved was what we may call the cellular, in which the whole animal or plant consisted of a single cell with a single nucleus. This fundamental type, although with great diversity of detail, is found in the great group of Protozoa, all of which are essentially single cells or quite simple colonies of cells.

Such a unit can never be much enlarged, for the simple reason that as its mass—that which has to be fed and provided with oxygen—increases as the cube of its radius, its surface—through which its food and its oxygen must come—increases only as the square. If a Protozoan

should treble its diameter without changing its shape, it would have multiplied its surface by nine, but its bulk by twenty-seven—three times as much. It is as if an island depending on imported food were to increase the population to be fed without a corresponding increase

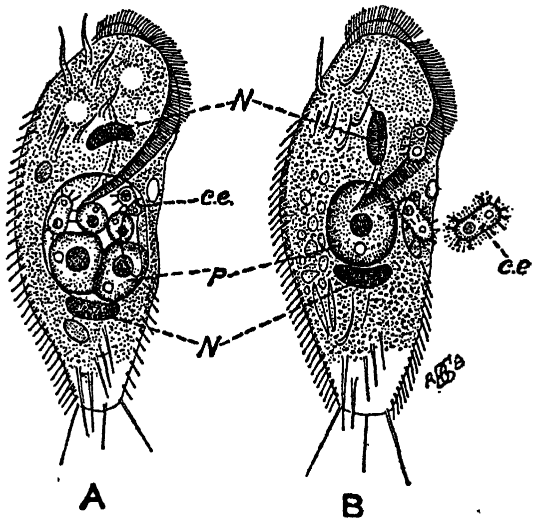


FIG. 62. To illustrate (A) the complexity which may be attained by unicellular organisms; (B) parasitism in Protozoa. The figures represent the Ciliate *Stylonychia mytilus* infested with parasitic Acinetans. Stylonychia possesses a special band of large cilia beating towards the gullet, long stiff cilia at the sides, and on the ventral surface large, often bent, organs consisting of several cilia fused together, by means of which it creeps over the substratum. *P*, parasitic Acinetans (Protozoa related to the Ciliates). These multiply within the host, and liberate small ciliated forms (*c.e.*) for dispersal. (Minchin, *Introduction to the Study of the Protozoa.*)

in docks, ports, and other import facilities. In spite of small size, however, some Protozoa attain very considerable complexity (Fig. 62).

Various methods for circumventing this limitation are found among Protozoa. In some the body becomes elongated, in others partly divided into a series of chambers, in others again, flattened and

ribbon-like; the number of nuclei in the cell is often correspondingly increased. But this never leads to any size which we could dignify as even moderate; and few are the Protozoa which are visible to the naked eye.

A great number are parasitic, and some are the active causes ot serious diseases, such as malaria, sleeping sickness, and one kind of dysentery. Some are even parasitic upon other Protozoa (Fig. 62).

Reproduction is by fission, usually, as in the cells of our own body, by equal fission; sometimes by multiple fission. In most species at least, a form of sexual reproduction occurs at regular or irregular intervals. It is interesting that in a number of cases the conjugating cells, instead of being sharply distinguished into male and female, as with the sperm and eggs of higher forms, are nearly or even wholly alike. Thus, the Protozoa teach us that the essential thing about sexual reproduction is not the existence of two sexes, but the union of two nuclei into one (Fig. 63).

One of the facts about Protozoa most curious at first sight is that in them natural death does not exist, or at any rate only affects small parts of the body. When they divide, or when they undergo sexual fusion, nothing is left which can be compared to a corpse, and the substance of the original individual becomes directly transformed into two new individuals. The only death is accidental death, due to enemies or to bad conditions. Natural death has not yet appeared.

Increased size (up to a certain but very large limit) is obviously in many ways of biological advantage. A larger organism is less at the mercy of external agencies, less liable to the attacks of enemies. It is only when bulk is very great that serious disadvantages arise.

Many bacteria are so small that they still show "Brownian movement"; in other words, their mass is so little larger than that of a molecule that the random movements of the molecules of the liquid in which they live can batter them and throw them from side to side. In most Protozoa and all higher animals this is no longer possible.

The force of surface tension is enough to catch and hold fast many small insects if they fall on to still water, while no vertebrate has to face this inconvenience. Or again, the fastest-swimming Protozoa, or the little Crustacea called Copepods, or the larvæ of crabs and lobsters, are powerless in the ocean currents which a herring or a

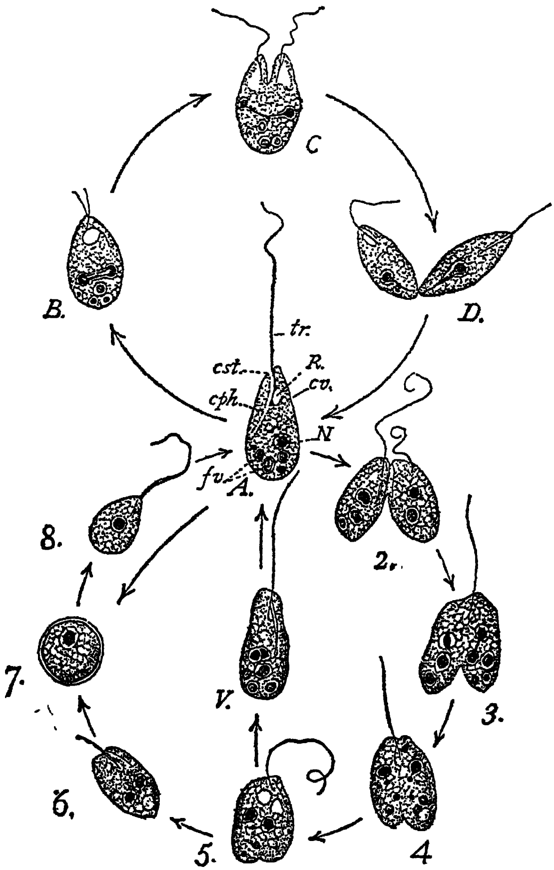


FIG. 63. Structure and life-cycle of a Protozoan (*Copromonas*). The animal is a cell with a single nucleus (*N*), and a long whip-lash or flagellum (*tr.*) with which it swims. Food (*fv.*) is taken in at the mouth (*cst.*) into the gullet (*cph.*) and comes to lie in the protoplasm of the cell. *B*, *C*, *D*, asexual multiplication by simple fission. In *B*, the nucleus is dividing; in *C*, the body has begun to divide; in *D*, division is just completed. 2–8, sexual fusion. Two similar individuals become attached (2) and behave as gametes, fusing their cell bodies (3–6) and nuclei (7) to form a single cell or zygote. After passing through a resting stage (7) this emerges (8) and grows up to the normal form (*A*) once more. Sometimes, as at *V*, the zygote does not pass through the resting stage; at other times a normal individual passes directly into a resting stage (*A*–7) without sexual fusion.

mackerel breasts with ease, while the elephant or the deer crashes through saplings each of which is a world to hundreds of small creatures.

A method adopted by many Protozoa for reaping some of the

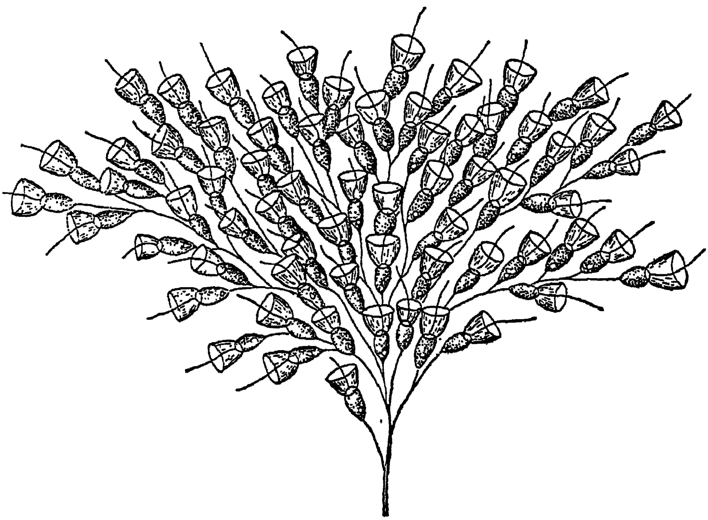


FIG. 64. A Protozoan Colony, without division of labour. The animal *Codosiga* belongs to the Choanoflagellates, a group of Flagellates in which a transparent collar of protoplasm surrounds the flagellum. The same arrangement is found in the cells of the inner layer of sponges. The colony is formed through the failure of the daughter individuals to become completely separated after fission.

advantages of size without the necessity for enlarging the individual cells is the formation of colonies. When fixed, these can produce strong feeding currents by the united action of all their cells, and can raise themselves on a common stalk beyond the competition of the common herd of non-colonial unicellular animals and plants on the surface of the same stick or stone, while, when free-swimming, they can develop greater speed (Fig. 64).

Sometimes a division of labour is found between different individuals of the colony, some serving for locomotion and feeding, others solely for reproduction. When this is so, it is really hard to say whether the colony is to be considered as a simple colony, a mere

aggregate; or as itself individual—a compound individual of a different grade from the single cells which compose it (Fig. 65).

Although the actual links are missing, there can be little doubt that all higher animals arose from Protozoa in this kind of way—by the aggregation of a number of cells into a colony, followed by a division of labour in the colony, first between reproductive cells and the others, which now merit the name of *somatic* or body-cells, and finally, by a further division of labour among the somatic cells into two layers, the outer protective and the inner nutritive.

This particular step in evolution seems to have been taken twice over by different animals, leading on in one case to the sponges, in the other to the whole of the rest of the animal kingdom.

Sponges are almost unique among animals for they have no mouth. They feed, as do so many of the smaller aquatic creatures, on microscopic particles of food extracted from a current which the animal passes through its body. In a sponge the current is sucked in through a great number of microscopic pores, and shot out at a single large opening, the *osculum* (Fig. 66).

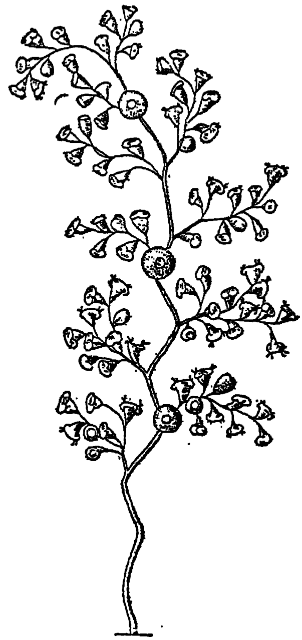


FIG. 65. A colonial Protozoan, *Zoothamnium*, in which division of labour has taken place. Feeding is done by the bell-shaped individuals, while the larger, round individuals reproduce the colony.

The cells that make the current are of a strange and interesting type, found nowhere else except in one small group of Protozoa. They each have a single actively beating flagellum, and are called collar cells because this is surrounded by a delicate, living, transparent funnel or collar, which seems to help entangle food particles (Fig. 64).

Each of the collar cells feeds separately from all the others; there

is no proper digestive cavity, no common function of digestion for the whole animal. In this the sponges betray how little they have advanced from a mere colony of separate cell units. The products of digestion diffuse out from the collar cells to other parts of the sponge, or may be transported by special wandering cells.

No sponges possess any sense organs or nerves, and the only movements they can execute are slow closures and openings of the osculum and pores. As might therefore be expected, they are all permanently fixed to the bottom throughout adult life. Their characteristic form is maintained by a skeleton of spicules or fibres. Our bath sponges, like many other species, are colonial, composed of a large number of sponge bodies aggregated together. This can be seen from the fact that they possess many oscula instead of only one.

The sponges thus represent an early side-line in evolution, along which life never developed far. They are often put in a group Parazoa, as distinguished from the true Metazoa or all the rest of the many-celled animals.

In the evolution of the Metazoa one of the earliest "inventions" must have been that of a mouth leading into a primitive digestive cavity. This enabled Metazoa to tackle relatively large animals and plants as prey, whereas a sponge, by its whole construction, can never rise above microscopic particles—sifting the water for the sake of its debris as men sift rubbish heaps for the few useful objects they may contain.

Metazoa, too, must have been fixed and sessile animals at the start, only later arriving at the emancipation of a free-swimming existence. Their simplest representatives are all put in the phylum Coelenterata. A primitive coelenterate is essentially a small bag or tube, its walls made of two sheets of cells. It is fixed at one end, and has a mouth, surrounded by tentacles, at the other. The mouth leads into a cavity called the coelenteron, because it fulfils the functions both of the coelom and of the enteron or gut of higher forms.

Such a type is illustrated in the common freshwater polyp Hydra, which catches water-fleas and such-like (relatively) large prey as it droops from a water plant with hanging net of extended tentacles. The prey is held and paralysed by a strange device. All over the body, and especially on the tentacles, are numbers of "thread cells," capable

when stimulated of throwing out a hollow barbed thread containing poison. These thread cells occur throughout the group; in some of the larger species, such as large jelly-fish, they can inflict unpleasant damage on man, and even those of a sea-anemone can pierce our skin and make it tingle (Fig. 67).

In yet another respect even the lowest coelenterates are more advanced than the sponges; they have muscles all along the body, so that the whole animal and not only isolated parts can be expanded or contracted. These muscles, however, are (at least, in the lower coelenterates) of a very primitive nature, since they are only the inner ends of the epitherial cells forming the chief bulk of the two layers of the animal. Division of labour has not gone so far as in higher forms: the same cell contracts with one part of itself, protects or digests with the rest. So a village shop often performs post office functions in one part, grocery functions in another, and stationery functions in a third, while in a town there will be separate shops for each function.

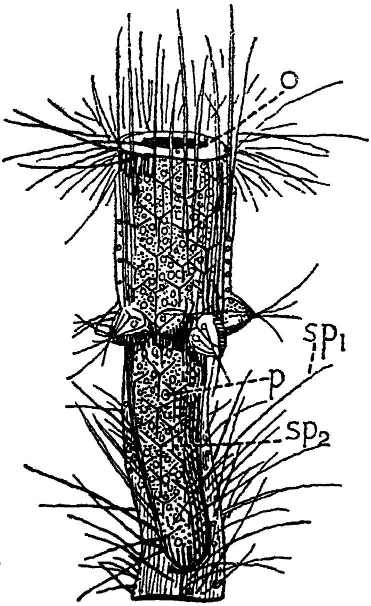


FIG. 66. A young Calcareous sponge (*Sycon*) soon after metamorphosis. *o*, osculum, from which the water is discharged which is taken in at the numerous pores, *p*. sp_1, long rod-like spicules, serving mainly for protection. sp_2, smaller three-rayed spicules embedded in the body wall and serving mainly for support. The animal is permanently fixed by the end opposite the osculum. The animal grows largely by the addition of thimble-shaped outgrowths, the flagellated chambers, the first row of which is seen in the centre of the body. (*Cambridge Natural History*, Vol. I, 1906.)

Most, if not all, of the group possess nerves, and at least scattered sense organs for perceiving touch stimuli.

The most important contribution made by coelenterates to evolution was perhaps the first emancipation of Metazoa from a

fixed existence on the bottom or attached to water plants or floating objects to become free-swimming.

Imagine a polyp like Hydra turned upside-down, the jelly between the two cell layers much thickened, and the region between mouth and tentacles pulled out. This would give a fair idea of the way in which a typical free-swimming coelenterate is constructed. Such

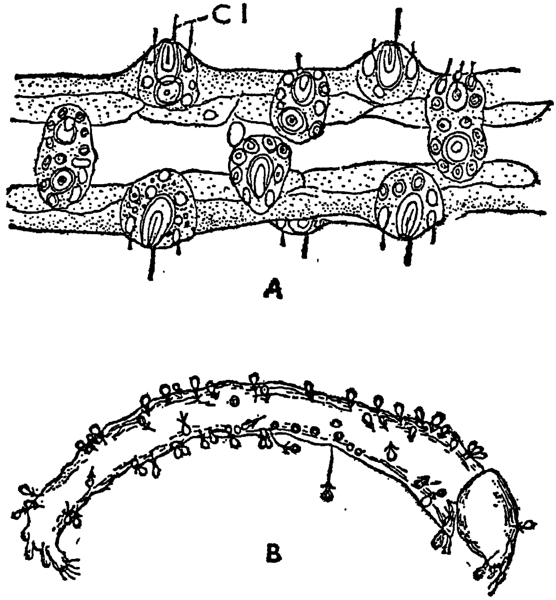


FIG. 67. (A) A portion of a tentacle of Hydra, magnified, showing a number of stinging capsules (nematocysts) contained within the cells (thread cells) which have formed them. From these cells project trigger hairs, *cl*, whose stimulation probably causes the discharge of the thread coiled up within the stinging capsule. The central cavity of the tentacle, which communicates with the general cavity of the body, is seen, and the two layers of cells, endoderm and ectoderm, which surround it. (B) The aquatic larva of an insect after being captured by a Hydra. It is stuck all over with stinging capsules. Their threads have been discharged into the animal's tissues, and their basal barbs are seen. (Hegner, *Introduction to Zoology*, 1910.)

animals are called Medusæ, or jelly-fish (Fig. 69). While the smallest are microscopic, many are over a foot across, and a few are much larger still (up to nearly 8 feet in Cyanea) and must weigh at least half a ton.

In spite of their size, however, their swimming is of a rudimentary

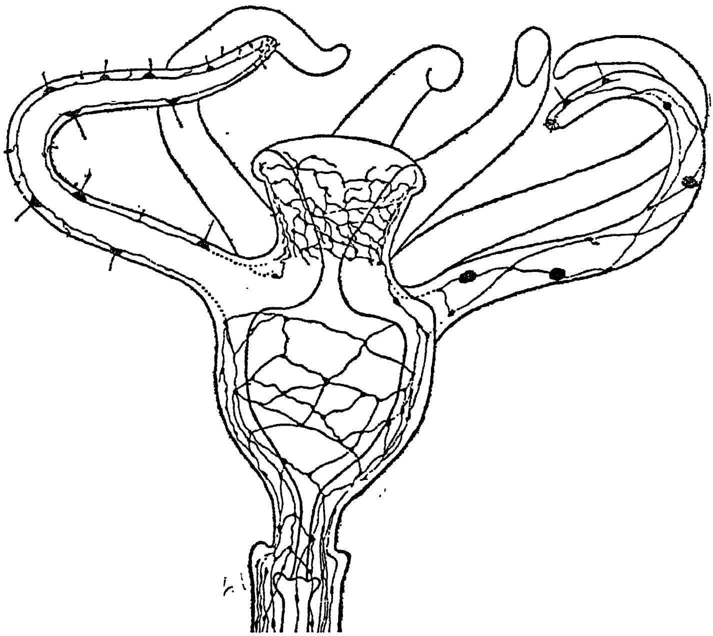


FIG. 68. Diagram of the nerve-net in a Hydroid Polyp. The thick black lines represent the outer and inner margins of the body wall. The nerve-net is figured in surface view over one tentacle (on the right), the base of the mouth, and the main part of the body and stalk. Note the absence of any central nervous system, but the greater concentration of the net in the more sensitive mouth region. The black dots on the nerve-net are bodies of nerve-cells. The hemispherical black bodies in the tentacles are nettle cells.

kind. They are never swimming anywhere in particular, but drift near the surface of the sea; all their muscular energy is devoted to preventing themselves from sinking. Almost the only movement they can execute is the simple contraction of the bell, more strongly or less strongly according to circumstances. Accordingly, they have no need

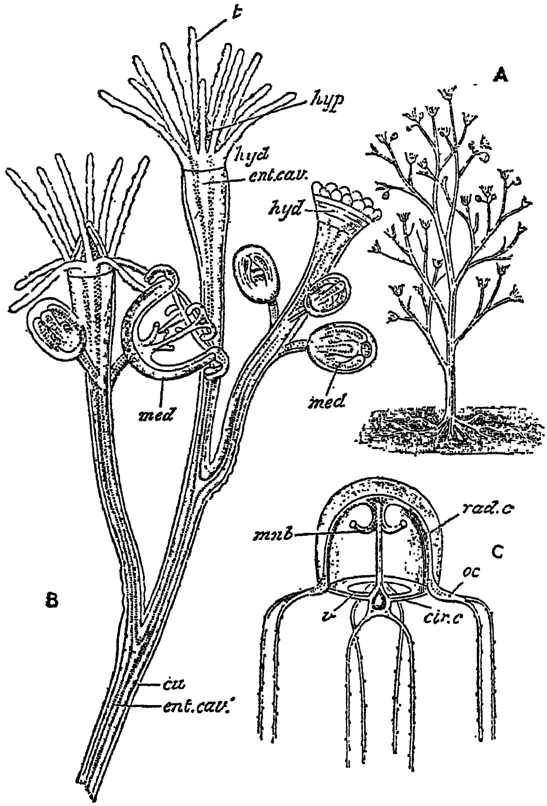


FIG. 69. A Hydroid Polyp (*Bougainvillea*). (A) A small colony, natural size. Note the root-like stolons acting as hold-fasts. (B) A portion of a colony, magnified, showing nutritive individuals or hydranths (*hyd.*) and sexual free-swimming individuals or medusæ (*med.*) in various stages of formation. The individuals are all joined to a common stem, through the whole of which runs a common cavity (*ent. cav.*); the colony is supported and protected by a thin, horny skeleton (*cu.*). (C) A medusa or jelly-fish after being detached from the colony. The mouth is in the centre of the handle-like structure (*mnb.*) which protrudes downwards into the hollow of the swimming bell. Four radiating canals (*rad. c.*) connect the stomach above the mouth with a circular canal (*cir. c.*). At the base of each pair of tentacles is an eye spot (*oc.*) and a balancing organ. (After Allman, from Parker and Haswell, *Textbook of Zoology*, I, 1897.)

of an elaborated nervous system. As a matter of fact, that which they and other coelenterates possess is of a primitive type known as a nerve-net, in which the sense organs communicate with a network of nerve-cells branching all over the body, which in their turn communicate with the muscles.

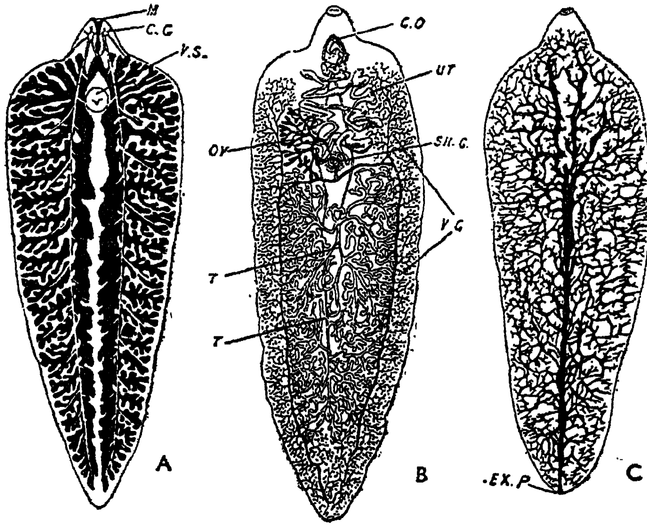


FIG. 70. The anatomy of the Liver Fluke (*Distomum hepaticum*). (A) *Digestive and nervous systems.* The gut (black) is much branched. The central nervous system consists of a pair of main lateral trunks arising from a cerebral ganglion forming a collar round the pharynx. *M.*, mouth. *C.G.*, cerebral ganglion. *V.S.*, ventral sucker. (B) *Reproductive system.* All parts of this are branched. *G.O.*, genital aperture. *T.*, testis. *Ov.*, ovary. *Y.G.*, yolk gland. *SH.G.*, shell gland. *UT.*, "uterus" (receptacle where eggs develop after fertilization. (C) Much-branched *excretory system. Ex.P.*, excretory aperture. (D) Enlarged view of region near genital aperture.

The main nervous system of a vertebrate can be compared with an elaborate telephone system. The nerve-net is somewhat like a telephone system in which every time any receiver was taken off its hook all the telephone bells of all the subscribers would start ringing. This sounds inconvenient; but, as a matter of fact, as the "subscribers" are the muscle fibres, and as in jelly-fish they are all engaged in doing the same job in the same way, it is a good thing that all of them can

be speeded up or slowed down by a single stimulus to one of the sense organs.

In ourselves the intestine has to carry out movements of the same sort—the constant succession of peristaltic waves of contraction may be slowed, or accelerated, or in rare cases reversed in direction, but nothing more elaborate. And it, too, possesses a nerve-net not unlike that of the coelenterates.

If one desires to visualize evolutionary progress, one may do worse than to remember that in its nervous and muscular organization a jelly-fish, for all its beauty, is nearly on the level of the human gut.

Colony formation is very frequent in coelenterates, largely as a consequence of the ease with which budding occurs (Fig. 69). Corals are coelenterates and coral reefs the accumulation of the skeletons of these little colonial polyps. Although there are very few coral-like animals round the English coasts today, in part of the secondary geological period they were abundant. Oxford was near the centre of a coral sea, and on the hills round the town one can dig out any quantity of fossilized corals (Plate 20 (i)).

Not only are some medusæ very large, but the sea-anemones, too, have found means to multiply very considerably the original insignificant size of the primitive polyp. This they have done by increasing the thickness of jelly between their two layers, and by dividing their enlarged central cavity by a series of strengthening partitions.

But both these and the jelly-fish seem to have been blind alleys for developing life. The main stream flowed elsewhere.

All higher groups abandon the radial symmetry of the coelenterates and are (permanently or in early stages) bilaterally symmetrical and therefore have a definite head end and a back and belly. They also all early develop three main layers. The outer produces nervous-system, sense organs, and outer skin or epidermis; the inner produces the digestive tube and its appendages like digestive glands, etc.; the middle produces muscles, connective tissue, reproductive organs, blood system, and, in vertebrates, kidneys and skeleton.

The lowest of these three-layered forms are the flatworms, with which we have already become familiar in the person of the Planarian (p. 246 and Fig. 40). They possess no skeleton, no respiratory organs, no blood system, no body cavity, but only cellular "packing" round

the main organs, and only one aperture to the digestive cavity. Owing to the absence of blood circulation, they must in the first place be flat and leaf-like, to put all tissues within range of oxygen diffusing from the surface. In the second place, they must have their gut and all their organs finely branched (Fig. 70). This is necessary so that the tissues of all organs may be able to acquire food by diffusion directly from the gut. Once a circulatory system was evolved, all necessity for this extraordinary branching of organs came to an end. The flatworms, however, show a great advance on the coelenterates in possessing a definite central nervous system with head ganglia or primitive brain.

Space forbids more than a bare mention of two considerable other groups of worms, the round-worms or Nematodes and the Nemertines. They are chiefly of interest to us in that they show stages in the development of new cavities in their bodies in addition to the digestive tube. The round-worms have a spacious cavity which probably corresponds to the blood system of higher forms, although there is no true circulation in it, while the Nemertines show what is probably the beginning of the coelom. In addition, their digestive tubes have acquired a second opening, the anus, at the opposite end to the mouth, so that the fæces can for the first time in Metazoa pass out at a different aperture from that at which the food is taken in.

The tiny rotifers or wheel animalcules, familiar to all who use the microscope to investigate the population of freshwater ponds and ditches, are at about the same level of evolutionary advance as the round-worms. They very much resemble the larvæ of segmented worms and of molluscs, however, and are perhaps to be considered as animals which have become degenerate by never growing up but remaining permanently in an early stage of what was once a longer development.

Save for a few exceptional cases, all the remaining members of the animal kingdom, which are sometimes grouped together as Coelomata, are characterized by the possession of three main layers—an anus, a true body cavity or coelom, and a true blood system.

The advantages accruing from these advances are clear. In the first place, the contraction of gut and muscular body wall can now become more and more independent of each other, instead of the gut being

squeezed or pulled out according to the movements of the whole animal. In the second place, a sort of trap is interposed between the gut and the rest of the body, in which poisons and actual bacteria passing in from the digestive tube can be dealt with. In higher vertebrates patches of tissue which produce white blood-corpuscles are found scattered over the inner wall of the coelom where it covers the intestine; while in many low forms such as worms, many white corpuscles laden with waste materials are found in the coelom, there to break down, and to be carried away by the excretory organs.

Thirdly, as the bulk of animals becomes greater, it becomes more and more necessary to provide greater absorptive surface in the intestine. We have already seen that in any structure which is enlarged without alteration of shape, bulk increases as r^3, but surface only as r^2. Thus, it will be of no avail to keep the same proportions of intestine as the animal grows larger, but new arrangements must be made for making the surface more or less proportional to r^3. In some animals, like the earth-worm, this is accomplished by a simple infolding of one side of the straight gut; in others, like the sharks and dogfish, by a spiral valve in the intestine, down which the food must travel, as if down a shallow spiral staircase instead of dropping directly down a shaft. But in the majority of large animals the difficulty is surmounted by coiling the gut. In a tadpole the intestine is packed like a watch-spring; even in man the gut is about four times as long as the whole body; while in herbivorous mammals it is often relatively much longer. Only by the existence of a space such as the coelom would it be possible for the gut to become coiled in this way.

The whole problem of size in animals is of great interest. As the accompanying table (pp. 331–335) shows, the range of size in organisms is enormous, a big tree being as many times larger than a small bacterium as the sun is larger than the big tree (*see* p. 331). It is startling to find that there exist adult insects, with wings and legs, compound eyes and striated muscles, smaller than the human ovum; that jelly-fish may reach nearly a ton in weight; that the largest elephant has clearance top and bottom inside a whale (Fig. 92); or that there are Protozoa larger than the smallest Vertebrates. Many problems as to limitations of size are suggested by such a table, but they cannot be discussed here.

FIG. 71

TABLE OF COMPARATIVE SIZES

grams

$10^{57} \times 1{\cdot}8$ = minimum weight of universe

$10^{33} \times 2$ = weight of sun

$10^{27} \times 6$ = weight of earth

$10^{24} \times 7$ = weight of moon

10^{10}

Big trees of California (by volume, c.c.)

10^{9}

Largest oaks and elms (by volume, c.c.)
Largest whales

10^{8}

Largest Dinosaurs (Brontosaurus, Diplodocus, etc.)
Largest fish (basking shark)

10^{7}

Largest extinct purely terrestrial animals (extinct elephants)

NOTE.—The figures are for adult specimens only. (For smallest parasitic Protozoa, the full-grown form found in the Vertebrate host has been taken.)

The sizes are given as weights in grams (except in a few stated cases, where volumes in c.c. are given). In most organisms, weight in grams will be close to (usually slightly greater than) volume in c.c. It will be seen that the largest organisms are 10^{25} as large as the smallest known. The sun is over 10^{24} times as large as the largest organisms; the whole universe, according to calculations based on the Einstein theory, at least 10^{24} times as large as the sun. The smallest organism is 10^{12} as large as the smallest known particle of matter. The range of size of organisms is therefore over a quarter of the total range of size within the universe.

The size ranges of different groups (number of times the largest exceeds the

Largest existing purely terrestrial animals (elephant, rhinoceros)

Largest molluscs (giant squids)

10^6

Very large cart-horse

Average cart-horse and cow; red deer, alligator

Largest jelly-fish (Cyanea arctica)

Largest flightless birds (moa, æpyornis, large ostrich)

Very stout man

Largest lizards (Varanus komodensis)

10^5

Average man and woman; sheep, wolf

Largest flying birds (condor, albatross, tame swans)

Largest bivalve molluscs (Tridacna, etc.)

Largest arthropods (Japanese spider-crab, very large lobster)

10^4

Fox, cat; bustard, wild swan

Fowl, rabbit, largest frogs, largest cell (yolk of æpyornis egg)

Largest hydroid polyp (Branchiocerianthus)

Largest Brachiopods (Productus giganteus), largest Echinoderms (sea lilies, urchins, sea cucumbers and starfish)

Largest worms (e.g., Eunice Rousseaui)

10^3

Pigeon, kestrel, herring, rat, bull-frog

smallest number of the group) are very different. That of the Vertebrates is 10^{10}. Among the Vertebrates the mammals have 10^8 (land mammals 10^7), birds 10^5 (flying birds only 10^4), fish 10^8. The Arthropods have also 10^{10} (insects only 10^6). The molluscs and Coelenterates have the largest value of any Metazoan groups, viz., 10^{11}. The Brachiopods, Echinoderms and Rotifers have all small ranges (10^7, 10^6 and 10^5 respectively); that for the Rotifers is only 10^4 if the small degenerate males are excluded. Worms have a value of 10^{10}. Free-living Protozoa have a range of 10^{11}, equal to the highest in the Metazoa. If the parasitic forms are included, the range is increased 100 times, to 10^{13}, thus giving the greatest value for any group.

10^2

Thrush, sparrow, mouse, common frog
Largest insects (Goliath beetles)
Largest spiders (South American bird-eating spider)

10^1

Wren, willow warbler
Smallest mammals (pygmy shrew)
Largest non-colonial Protozoa (Nummulites—all now extinct)
Smallest birds (humming-birds)
Common earth-worm

10^0

Honey bee; largest ants
Amphioxus
Smallest fish (Cyprinodonts, e.g., Heterandria formosa)

10^{-1}

Smallest vertebrates (tropical frogs, e.g., Phyllobates limbatus)
House-fly, most ants

10^{-2}

Largest British water-flea (Daphnia)
Hydra fusca, smallest Echinoderm
Largest Rotifers

10^{-3}

Smallest Brachiopod (Zellania or Thecidia), common flea
Average Daphnia

10^{-4}

Smallest molluscs (e.g., Acme stussineri)
Small Daphnia
Medium-sized human striated muscle-fibre
Most parasitic Chalcid wasps

10^{-5}

Human ovum
Smallest insects (beetles and parasitic Chalcid wasps)
Smallest Polychæte worms (e.g., Syllides opisthodonta)

Smallest Crustacea (Daphnids)
Smallest Coelenterate (Microhydra)

10^{-6}

Large Paramecium
Large sensory neuron of dog (cell-body alone, without axon and dendrites)
Smallest worms (Archiannelids)
Smallest female Rotifers

10^{-7}

Average Vorticella
Largest vertebrate red blood corpuscles (amphibian, e.g., Amphiuma)
Smallest male Rotifers (smallest Metazoa)
Human smooth muscle-fibre from intestine
Human liver-cell

10^{-8}

Cell-body of small sympathetic neuron (dog)
Dysentery amœba

10^{-9}

Islet cell of human pancreas
Frog's red blood-corpuscle
Trypanosome of sleeping sickness
Human white corpuscles

10^{-10}

Human red blood-corpuscle
Maximum size of malarial parasite in man
Human spermatozoon
Smallest free-living Protozoa (Monas)

10^{-11}

Anthrax bacillus

10^{-12}

Tubercle bacillus

Bacteria (cocci) of pus

Smallest parasitic Protozoa (Theileria in ox blood-corpuscle)

10^{-13}

Average cocci (round bacteria)

10^{-14}

Smallest visible bacteria (e.g., Bovine pleuro-pneumonia)

Spherical objects at limits of microscopic vision ($0{\cdot}2\mu$)

10^{-15}

Small filter-passing organisms ($0{\cdot}1\mu$ diameter)

10^{-16}

10^{-17}

? a single hereditary factor (gene)

10^{-18}

Hæmoglobin molecule

10^{-19}

Egg-albumin molecule

10^{-20}

Peptone molecule; fat molecule

10^{-21}

Glucose molecule

10^{-22}

Water molecule

10^{-23}

Hydrogen atom

10^{-24}

10^{-25}

10^{-26}

10^{-27}

An electron

10^{-28}

One of the most primitive groups of definitely coelomate animals is the Annelids, or segmented worms. These include the familiar earth-worms and their less familiar small freshwater relatives, the

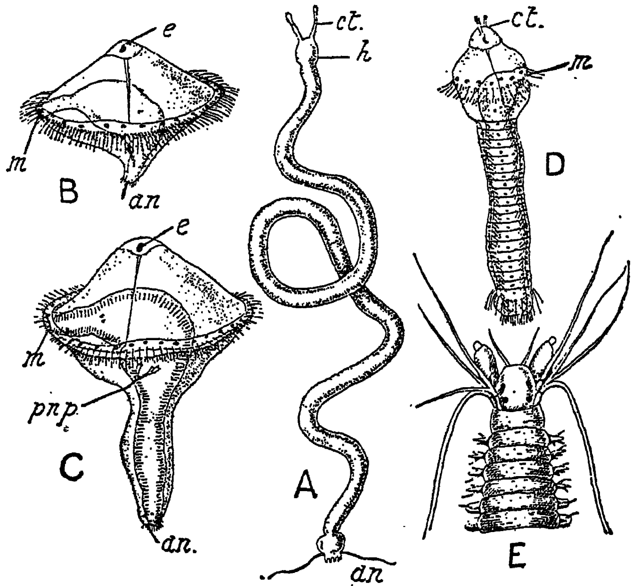


FIG. 72. Development from the early larva onwards, of the marine Annelid worm *Polygordius*. (A) The adult worm, dorsal view: *ct*, tentacles; *h*, head; *an*, anus. (B) Early larva (*trochophore*): *e*, eye-spot on sensory region (apical plate); *m*, mouth and intestine with anus, *an*. In front of the mouth a circular band of long cilia. (C) Late larva. The trunk region has elongated: *pnp*, larval kidney. (D) The larva is metamorphosing into the adult form (lower magnification). The trunk is still longer and has become segmented. The tentacles have appeared. The head region has decreased in size. (E) Anterior region of a Polychaete worm, the common sand-worm *Nereis*. The body-segments bear primitive appendages (parapodia). The parapodia of the head region are much modified. Tentacles and eyes are present.

marine group called Polychætes or "many-bristled," on account of their numerous swimming or crawling bristles and spines on each segment (the lugworm is a familiar example); the leeches, and some little-known aberrant types.

One of the important characteristics which these possess is segmentation. Of the three highest phyla of animals, the molluscs, arthropods and vertebrates, it is no coincidence that two, and the two most successful, are segmented. The meaning of segmentation is thus worth some study (Fig. 72).

All segmented forms are alike in certain respects. They all possess a small region in front of the mouth in which the brain, or its first evolutionary rudiment, is lodged. The trunk consists of a whole series, often a hundred or more, of segments, each one similar to all the rest in original plan. These are formed during development in a growth zone near the hind end, and this growing-region often continues active throughout life. Thus, the trunk region is, in a sense, repeated a number of times. Such segmentation is called *metameric*.

What are the advantages of such a construction? They are several. In the first place, the animal obtains any advantages of increased size that it would reap through colony formation, but with the fundamental difference that the numerous identical parts, instead of being independent of and perhaps at cross purposes with each other, are all under the control of the single anterior region, so that it is an organism of unified action from the first. Then division of labour can step in, just as it can among the members of a colony, and modify different segments for different functions, so that high specialization is easily achieved.

One of the earliest advances to be found in segmented animals is that of head formation. The primitive region in front of the mouth scarcely deserves the name of *head*. Gradually, however, several of the next following segments become firmly joined to it, their nerve ganglia in particular all being fused to form a single brain of compound origin. At the same time, more and more elaborate sense organs, more and more elaborate jaws and mouth parts, are evolved in connexion with what we can now call a *head*.

The Annelid worms never get very far along this line. Their chief interest to the evolutionist lies perhaps in the presence in their most typical representatives of outgrowths all along the body, one to each segment, called *parapodia*, which one might translate as "almost feet." They consist of protuberances on either side of each segment, each furnished with a battery of bristles and hairs of various shapes.

These sometimes serve for burrowing, sometimes for crawling, sometimes for swimming; there can be little doubt that from something of their type were evolved the limbs of crustaceans and insects.

Many worms have red blood, red with a hæmoglobin similar to that found in our own veins—a good example of the unity underlying very diverse forms of life. Others, however, have blood which is

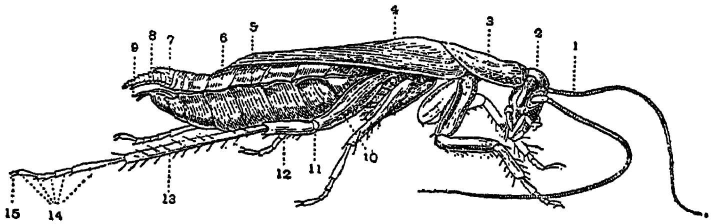


FIG. 73. Side view of a male cockroach (*Periplaneta orientalis*). 1, antenna; 2, head, showing the large eyes; 3, first segment of thorax; 4, wing; 5, joint (of soft cuticle) between hard dorsal and ventral plates (of 5th segment of abdomen); 6, 7, dorsal hard plates of 6th and last segments of abdomen; 10–14, the five main regions of the insect limb; 15, claws.

colourless, blue or even green; in some cases the blood pigment contains copper or zinc instead of iron.

Worms play a great role in the soil; but that is a story every one should read for themselves in Darwin's book on earth-worms.

From some type like that seen in marine Annelids there probably sprang the great group of Arthropods—the largest group of the animal kingdom in respect of numbers, and in some ways the most specialized and even the most advanced.

The decisive steps that they took in their evolution were these. In the first place they have all encased themselves in a hard covering made of a horny substance called chitin. This, by giving the possibility not only of unyielding attachment for muscles, but also of a fixed and definite shape, made rapid locomotion possible. The primitive parapodia of the worms have been improved and converted into definite appendages, each consisting of a number of hinged joints. In all Arthropods, marked division of labour has set in among the appendages, so that between them they carry out at least three functions. Some, like the antennæ, have become sense organs, the

majority are used as limbs for walking or swimming, and the rest are modified into feeding organs, taking the place of our lips, jaws, teeth, and tongue (Fig. 73). In the higher members of the various Arthropod groups, the nerve ganglia become concentrated near the anterior end, thus giving greater centralization of nervous control (Figs. 74, 75).

The number of segments may become fixed and definite, while the head is always a sharply defined region. Curiously enough, neither cilia nor flagella, for which many uses are found elsewhere, from the lowest to the highest animals, are to be found in any Arthropod. The Nematodes are the only other group without cilia.

The most successful of aquatic Arthropods are the Crustacea, ranging from the little water-fleas and tiny forms like Calanus, which constitutes one of the main sources of food to many marine fish, up to lobsters and crabs. Shrimps, prawns, hermit crabs, wood lice, sand hoppers, crayfish, are all familiar members of this great group (Plate 2).

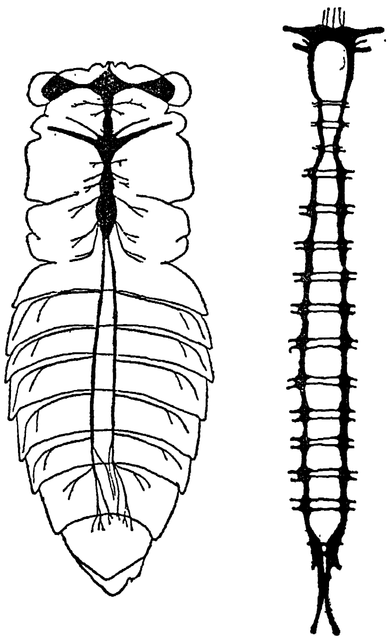


FIG. 74. Concentration of the nervous system in Arthropods. (*Right*) Central nervous system of a primitive crustacean (*Branchipus*). The two lateral trunks of the nerve-cord are separate, connected across the middle line by commissures. There is a ganglion in every segment. A few of the anterior segmental ganglia have coalesced to form a primitive brain. (*Left*) Central nervous system of Seventeen-year Cicada. The lateral nerve trunks have united in the mid-line, and the segmental ganglia of the abdomen have migrated into the thorax. Here they form, with those originally belonging to the thorax, a single mass. Only nerves are found in the abdomen. The brain is much enlarged. (Smallwood, *Man, the Animal*, 1922.)

Although a few Protozoa and all earth-worms live *in* the soil and occasional flatworms and leeches are terrestrial, yet the Arthropods are the first phylum we have met, and the only one beside the molluscs and vertebrates, in which emancipation from a watery life has been achieved by the majority of whole classes or orders.

A few land crabs are known; but insects, myriapods (centipedes, etc.), spiders and scorpions are chiefly and typically land-dwellers, and it is especially among the insects that progress is most marked.

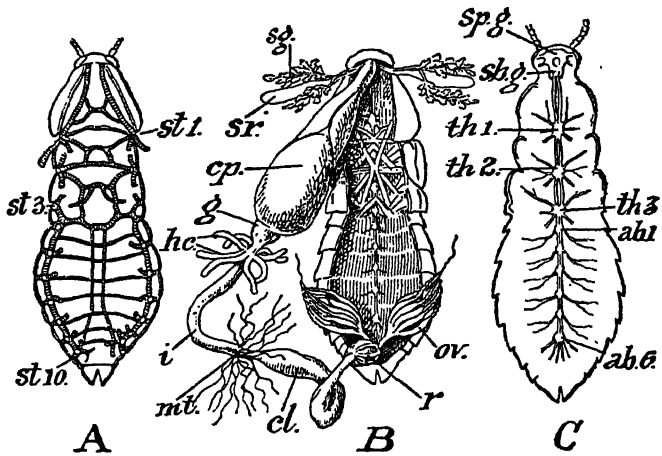


FIG. 75. Internal anatomy of the cockroach. (A) The main trunks of the tracheal system: *st* 1, 3, 10—1st, 3rd and 10th stigmata, or external apertures of the tracheæ. (B) Digestive and reproductive systems of a female: *cl*, colon; *cp*, crop; *g*, gizzard; *hc*, hepatic tubes (digestive gland); *i*, mid-gut; *mt*, Malpighian tubes (excretory organ); *ov*, right ovary (the separate egg tubes, with the smallest eggs towards the blind end, are seen); *r*, rectum; *sg*, salivary gland with receptacle, *sr*. (C) Central nervous system: *ab* 1, 6, 1st and 6th abdominal ganglia; *sb.g*, sub-oesophageal ganglion; *sp.g*, brain or supra-oesophageal ganglion; *th* 1–3, thoracic ganglion. The double commissures between the ganglia are clearly shown.

Insects possess a remarkable method of breathing, wholly different from ours. Their whole body is penetrated by a network of air tubes or tracheæ (Figs. 21, 75). By this means oxygen and carbon dioxide are taken directly to and from the tissues, so that the blood has no concern with respiration, but only serves to transport food and waste

products. As a secondary consequence of this, the blood circulation need not be, and is not, rapid; and the heart is of a comparatively low type.

Not content with conquering the land, the majority of insects are also at home in the air—a double achievement only found elsewhere among certain groups of vertebrates. Curiously enough, instead of using any of their existing limbs for flight, as have all flying vertebrates—whether flying-fish, flying-frogs, flying-lizards, pterodactyls, birds, or bats—they have employed as wings two pairs of quite new structures growing out from the upper part of the thorax, and probably developed from a kind of gill.

Every one has heard stories of the extraordinary capacities of various kinds of insects. One wasp has been seen to use a stone to pound down earth over its eggs—the only tool-user but man. The social life of bees and ants is more complicated than that of any other animal except ourselves. In a beehive, the newly emerged bees clean and prepare the cells to receive new eggs; after this, they help in keeping the temperature of the brood up when needful by clustering in dense masses over the nurseries. They probably also ventilate the hive by fanning with their wings. When the workers are three days old they begin to act as nurses, feeding the grubs with honey and pollen; this nursing duty is given up by two weeks old at latest. When they are between five and fifteen days old they take their first flights out of the hive, thus gradually gaining a knowledge of the surrounding country. After this the young workers begin to collect food from the newly returned food gatherers, and store it in the storage cells of the comb. The growing workers soon add to these duties that of sanitary workers, keeping the hive clean and removing any corpses. The last task undertaken before going out food-gathering is that of sentry duty; the sentries examine every bee that alights at the entrance, and attack all robbers or unwelcome strangers.

Finally, when about three weeks old, the workers set out for their final task of gathering nectar and pollen.

Thus, there is a wonderful division of labour or allotment of tasks within the bee community, but the different jobs are not carried out by different worker castes, as was at one time supposed, but are allotted to different periods in the life-history.

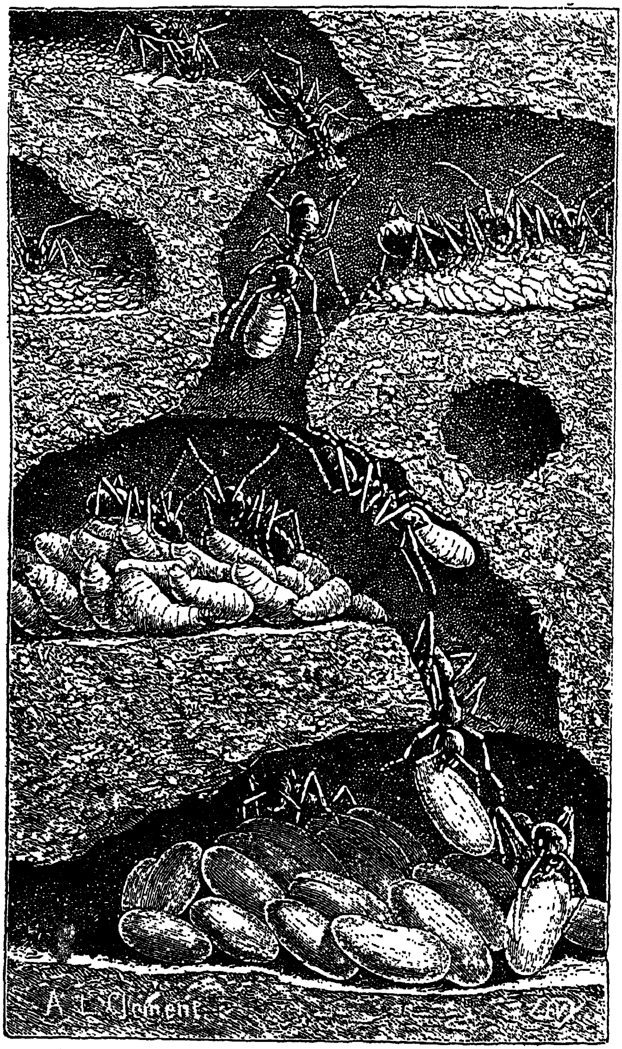


FIG. 76. Interior of an ant's nest to show the way in which the workers arrange the developing young according to their degree of development. In the top three chambers are very small larvæ (grubs); in the fourth, full-grown larvæ; and in the bottom chamber, pupæ. The larvæ and pupæ are often erroneously called "ants' eggs."

There are ants that keep slaves—some have gone so far as to lose the power of looking after themselves, and have to be kept clean and even fed by slaves of an alien species. Then there are ants which use their own babies, in the pupa stage, to build the nest; the pupæ have an abundant and sticky saliva, a gang of ants squeeze threads of this from leaf to leaf held in place by another gang (Fig. 77). Others have a caste of workers that gorge themselves with honey until their bodies are quite spherical, and then hang themselves upon the roofs of special "cellars" against the winter. When food is short, these living store-casks are taken down and "tapped" by the rest. There are ants which keep domestic animals—the little aphids—which they

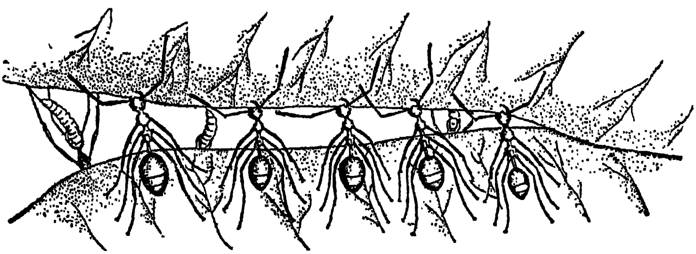


FIG. 77. Two gangs of workers of the ant *Oecophylla smaragdina* repairing a rent in the nest (which is made of leaves stuck together by silk threads). One gang is pulling the edges of two leaves close together, the others, on the inside of the nest, are carrying well-grown larvæ in their mouths. By squeezing, the larvæ are made to exude slimy threads which soon harden to silk; and the workers use these threads to sew the leaves together.

tend and keep for the sake of their sweet secretion, and there are ants which practise agriculture. They make subterranean hotbeds with pieces of leaves which they cut, and in these plant the spores of special fungi, sometimes only known in the ants' nests. When a queen goes out to found a new colony, she takes a pellet of the precious fungus with her in a special pocket below the mouth.

Insects appear to have been in existence for a longer time than vertebrates; certainly the highest insects such as ants have been in existence longer than the highest mammals. Why is it, we may well ask, that the vertebrates ever got the chance of rising? Why did not the insects come to occupy a predominant position among animals,

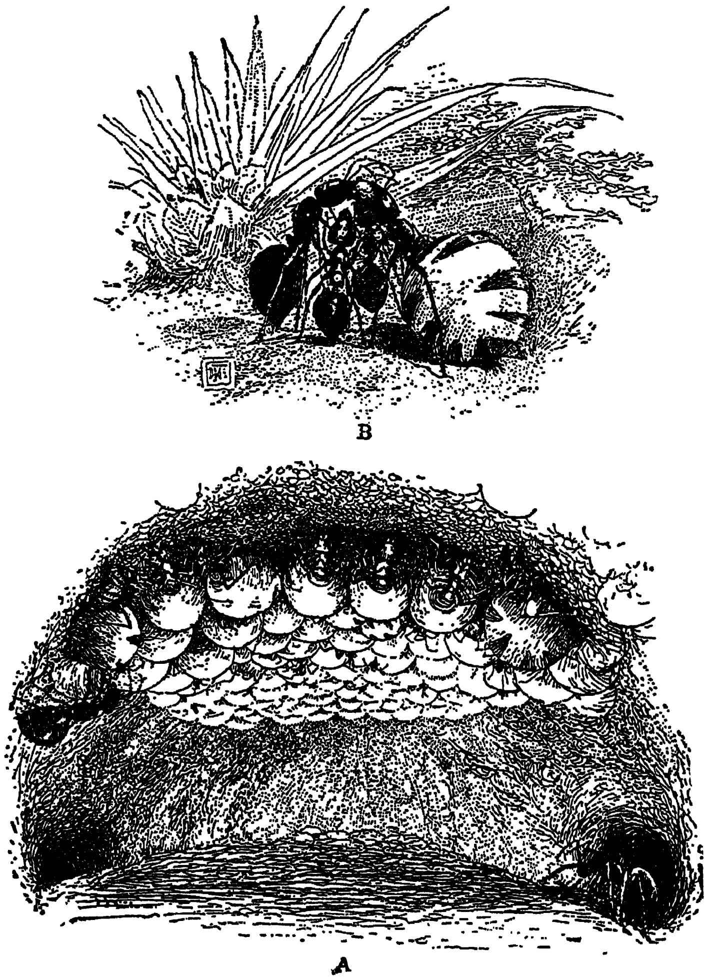


Fig. 78. (A) A store chamber of the honey-pot ant (*Myrmecocystus*). Certain workers gorge themselves with honey until their abdomens are quite spherical (note the light skin stretched between the dark plates of the external skeleton, which were originally in contact). They then hang themselves up in special underground chambers until there is a shortage of food, when they regurgitate their honey to the other workers (B).

and keep out intruders from their preserves?

The answer appears to be twofold.

In the first place, their cleverness and efficiency is far more a matter of inborn instincts than of learning, clockwork smoothness rather than discovery and choice. They can learn, but the power of learning is small, the elaboration and fixity of their instincts great. It is precisely the reversal of this relation between instinct and learning-capacity which finally enabled the vertebrates, in the person of man, to begin to rise above and to control the forces which up till then had controlled and moulded life.

Secondly, as it turned out, the typical structure adopted by the group carried irrevocably, within itself, a limit to any great advance in size.

The skeleton of an Arthropod is not only on the outside; once it is laid down it is dead. If growth is to take place, the animal must moult—the old skeleton be split and thrown off and a new one formed underneath. While the new one is being formed, the animal is naturally soft and defenceless.

As an Arthropod increases in size, for various mechanical reasons the bulk of the skeleton must grow not only absolutely but relatively bigger. The difficulty of emerging from the armour-plating becomes greater, and the time necessary for building up a new skeleton and hardening it with lime would be more and more prolonged. If there could exist a crab as big as a cow, it would have to spend more than half of its existence in hiding, waiting for its skeleton to grow after moulting. But such an animal could not exist. Even in water and without a skeleton a crab's body has some weight, and a crab of this size would at moulting flatten out like a gigantic bun. This would happen, of course, at a much lower size in land Arthropods, whose weight is supported by no circumambient water. And as a matter of fact, although we find moderately large marine Arthropods, such as the giant spider-crab, with a body a little bigger than a man's head and gigantic but thin legs, yet the largest purely land forms (excluding land crabs) are the big tarantula spiders, the bigger among the scorpions, the goliath beetles, and the giant swift-moth, none of which have a body (excluding limbs, wings and the tail in scorpions) of over six inches long.

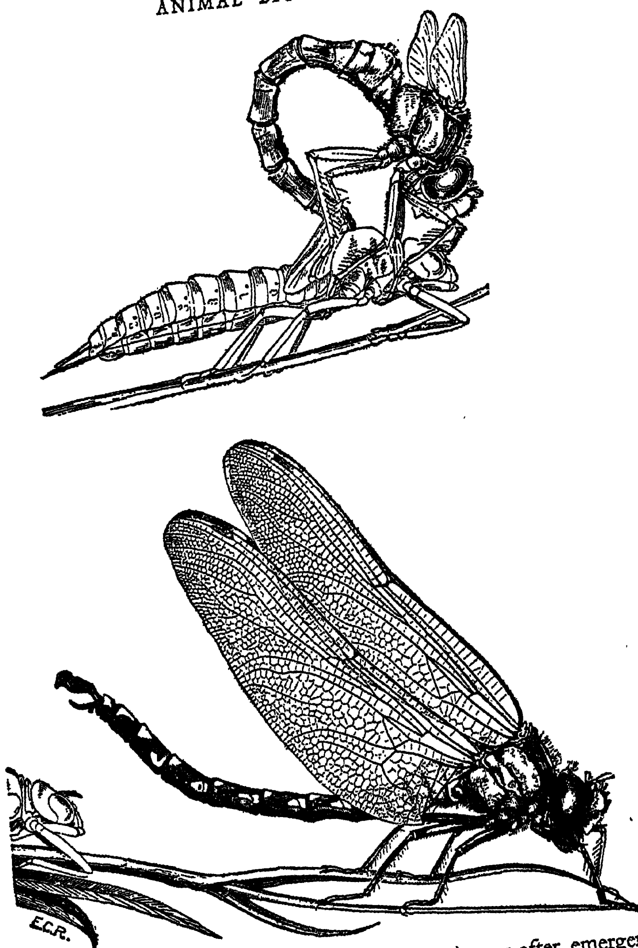


FIG. 79. Below, an adult dragon-fly (*Aeschna cyanea*) soon after emergence. The two very similar pairs of wings are drying in a vertical position. When dry, they are held horizontally. Note the huge eyes, the long segmented abdomen, and the three very similar pairs of legs arising from the three-segmented thorax. To the left, part of the larval skin from which it has emerged. Above, the same specimen emerging from the nymph (*larva*). The wings are still very small; they are later dilated by the fluid pressure of the blood. In dragon-flies the larva is aquatic, but not otherwise markedly different from the adult except in being incapable of flight. There is no resting stage (*pupa*) between larval and adult stages.

In order to obviate some of the difficulties which at each moult beset a complicated animal with external skeleton, in all the more specialized insects is found the plan of dividing life into two wholly distinct phases, with a metamorphosis between. In the first or larval phase the necessary growth is achieved, and the animal is very little else but a feeding machine—a butterfly's caterpillar, beetle's grub, or fly's maggot. Then comes transformation to a resting stage or pupa, during which the metamorphic transformation is accomplished—the white blood-cells break down the larval organs, and little reserve packets of cells grow up into the organs of the adult. Then from the pupa there emerges the reproductive adult or imago, capable generally of flight, active, endowed with efficient sense organs and wonderful instincts. In other groups there is no pupa stage, and the metamorphosis is less radical (Fig. 79).

Thus, in insects the larval stage is a new development, forced upon the higher members of the group by their very complexity, not as in Amphibia a primitive condition, the larval amphibian today living in the same way and in the same element as did the ancestors of the group in the remote past.

Two matters must detain us for a moment. The first is the social life of many insects. The bees, the wasps, the ants, and the termites all display a wonderful perfection of community life. Well-developed community life with organized societies only exists in the Arthropods and Vertebrates. These are two groups in which the formation of colonies with physically connected members, so frequent in lower forms, is absent. The meaning of this is simple. The animal community, like the colony, increases the size of the effective unit; it takes the place of the colony in groups above a certain level of complexity; and this for two chief reasons. First, it would be of no advantage, but of definite disadvantage, to have, in any animals so highly organized as insects or vertebrates, a colony composed of individuals joined to each other by physical connexions. A high type of animal is a high type largely by virtue of its elaborate organization for moving from place to place and for perceiving distant objects, and all this would be nullified by such an arrangement. On the other hand, the perfection of its sense organs and its brain enables it to communicate with its fellows and to possess instincts making for

concerted action. In a colony of polyps, the only way in which one polyp can help another is digestively; ants, however, will guide others to food they have found, and the adults will tend the larvæ. A community, in fact, is a colony held together by psychical instead of by physical bonds. The largest communities in the world are those of ants and of men. Some ant communities contain over half a million individuals. The largest human communities at present are the British Empire with about 460 million individuals, and China with about 420 millions.

In all social insects the great majority of individuals are "workers," incapable of reproduction. In ants, bees, and wasps the workers are modified females, while in termites both males and females have become unsexed. In many ants and termites the workers have become differentiated into several sub-castes, of which the largest act as soldiers.

The other point concerns the senses of Arthropods. Arthropods have progressed far in evolution, but along wholly different lines from those along which the vertebrates have travelled. As one would expect, they possess the same general kind of sense organs as vertebrates—for touch, smell, taste, sight and sometimes hearing—but these are often constructed on a plan wholly different from that of ours.

The sense of smell in insects, for instance, seems to depend upon the sensitive hairs in the feelers or antennæ. These are very highly developed in the males of some moths, such as the Oak-eggar, and enable them to find a female of the species, even if shut up in a box, at a distance of a mile or more.

The Arthropod compound eye, however, is perhaps the most remarkable of their sense organs. It consists essentially of a number of little elongated eyes placed side by side, and separated optically from each other by a black backing of pigment to each. The retina of each eye can only receive an impression of the tiny area of outside world directly in line with it beyond the window of its cornea. All the retinæ transmit their impressions to the brain, which must then receive a mosaic of separate images, and must then combine them to a single coherent picture. In some dragon-flies the huge compound eyes are composed of over 25,000 separate eyelets, and are curved so

that some of these point in every direction. A dragon-fly can look in front, and backwards, and sideways, and up, and down, all at once and without a movement of its head (Plate 20 (ii)).

Such eyes are probably more efficient than ours in some ways, such as in this matter of looking many ways at once, and in the detection of small movements of objects; they are, however, certainly less efficient in giving an accurate picture of the details and fine texture of objects, since our sensory units are smaller, and they have no focusing mechanism.

Insects, as we have seen, are usually small. Every one will have noticed flies and small beetles and moths struggling on the surface of water; they are so small that they are a prey to the surface tension of the surface film, and cannot get free. It is thus difficult for most insects to go to water to drink, like a land vertebrate (collectors of butterflies will have seen "blues" and other butterflies drinking—but always from moist soil, never from pools of water). It is possible that an unusual anatomical feature of theirs is to be associated with this fact. Their excretory organs do not open directly to the outside, but take the form of a number of thin tubes (Malpighian tubules) opening into the intestine (Fig. 75). This may possibly be a water-saving device. The hinder part of the intestine in man absorbs water; if it did the same in insects, all the water contained in the excretory fluid would be reabsorbed, and the animals would have to drink much less.

Of other Arthropods we can speak but little. Mention should be made of the wonderful crab Birgus, one of the few land-living Crustacea, whose claws are so powerful that they can open coco-nuts and even cut barbed wire; and then there are the spiders, which have developed a tracheal breathing system quite independently of the insects, and have the best developed courtship displays of any invertebrates, as well as rivalling all but the social insects in complexity of instincts.

There remain of the invertebrates the Molluscs, the Brachiopods, and the Echinoderms. The molluscs comprise the true "shell-fish," and are biologically an extremely heterogeneous group, ranging from tiny primitive worm-like creatures to the largest and most highly organized of all invertebrates—the squids and octopuses. They

all possess (besides other technical characters) a large fleshy organ of locomotion, the foot; and almost all have a shell; they differ from most other successful invertebrates in not being segmented. The most important are the "bivalves" (Lamellibranchs), and "univalves" (Gastropods), and the octopus, the nautilus, and their relatives (Cephalopods) (Fig. 80).

The bivalve molluscs are a degenerate group; their degeneration has come about through their adoption of sessile or semi-sessile habits. In practically all of them, such as the oyster, the mussel, the freshwater mussel, etc., the so-called "gills," though they still assist in respiration, are in reality mainly food-catching organs. They are very large and covered with cilia; the cilia produce a current, and the gills are so arranged as to strain off all small debris from this current. Their digestive system is so constructed that it cannot avail itself of large particles of food, and all particles above a certain size are side-tracked and ejected again if they manage to get in. The acquisition of food by these means does not require great intelligence or elaborate senses; and we find brain and distance-receptors very poorly developed in almost all members of the group.

The Gastropods are so called because (to quote Mr. A. P. Herbert) "They travel about on their tummy." The most remarkable fact about them is that they are not symmetrical; usually, as in the common snail, a large part of the body is twisted up into a spiral, the spiral being covered with a shell. Limpets, cowries, whelks, slugs, snails, periwinkles, sea-slugs, the pteropods that form the staple diet of whalebone whales—these are typical examples. They represent somewhat of a compromise in evolution between security and progress. The shell is a fine protection, but it is a very heavy piece of armour-plate. As a result, we usually find movement effected by simple crawling on the slimy under-foot; the snail is not only proverbial, but typical in respect of its slowness. Since they are free-moving, distance receptors are wanted; but since they move slowly, these sense organs are only moderately well developed. Most of the species are neither very small nor very big—from about a centimetre to a decimetre long; a few, however, reach greater sizes. One fossil tower-shell stands nearly five feet high, as you may see in the South Kensington Museum.

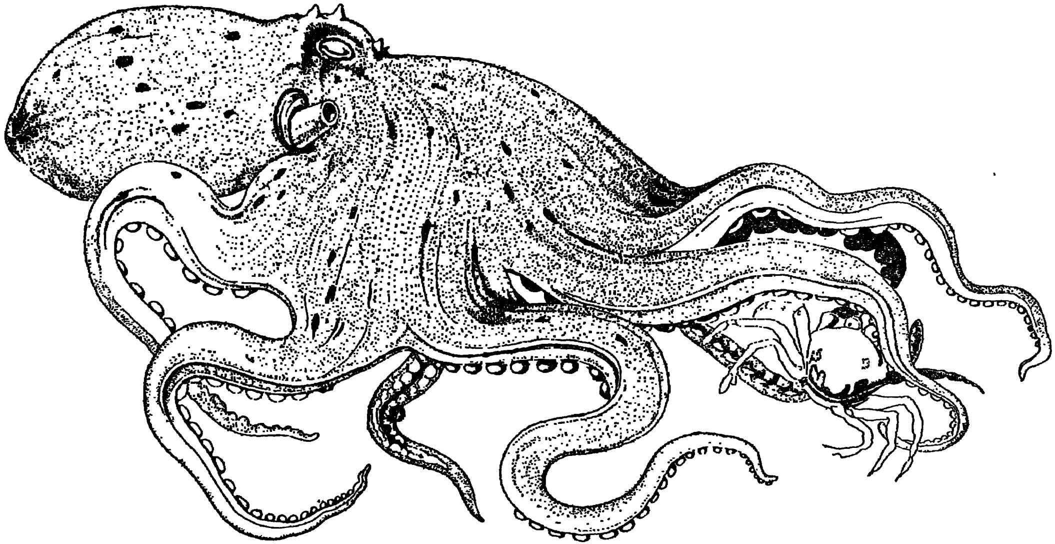


FIG. 80. A common octopus (*Octopus vulgaris*) seizing a crab. The foot of these animals is prolonged into eight "arms" provided with suckers. The mouth, with horny jaws like a parrot's beak reversed, is between the arms. The right eye is seen, also the funnel from which water is ejected from the mantle cavity. Water is drawn in round the mantle edge to aerate the blood in the gills. The animal can swim rapidly backwards by ejecting water violently through this funnel. It also crawls about by means of its arms. The body, containing the viscera, is on the left.

The highest molluscs, however, and in some ways the highest invertebrates, are the Cephalopods. The more primitive among them, such as the nautilus and the ammonites (now extinct, but once the dominant group), still retain a large protective shell. But in all the

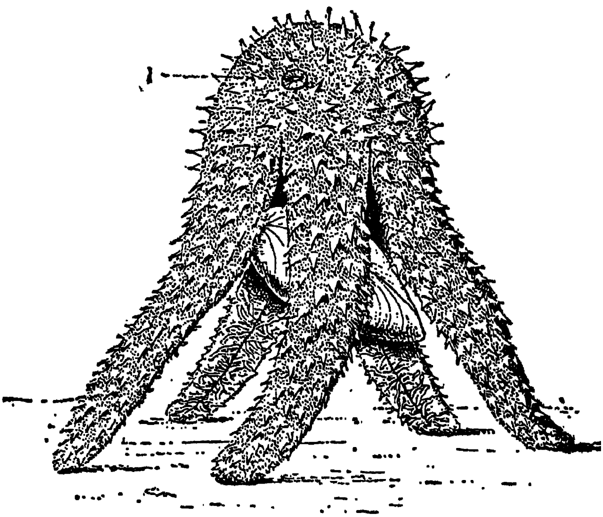


FIG. 81. A starfish (*Echinaster*) devouring a mussel (*Mytilus*). 1, Madreporic plate, through which water enters into the system of water-vessels, which help actuate the tube-feet by keeping them distended. By means of its tube-feet the starfish exerts a constant pull which eventually wears out the muscular resistance of the mussel. The starfish then protrudes its stomach out of its mouth and inside the shell of the mussel. Here it apparently digests the body of the mussel, the resultant fluid being sucked up into the rest of the digestive tube of the starfish. The starfish is depicted too much raised on the tips of its arms; it should be more crouched down.

highest forms the shell is quite internal and much reduced—transformed from external armour to internal support—or even absent: the "foot" has in these creatures become divided into eight or ten "arms" beset with suckers. In some of these higher forms an unusual method of rapidly moving from place to place has been evolved; they squirt out water forwards through a narrow jet and so move

quickly backwards. In others, muscular fins are developed along the sides, by means of which the animal can swim either forwards or backwards. In addition, some (such as the octopus) can clamber about on the bottom by the aid of their arms.

All are freely and often rapidly mobile, and not stuck to the bottom like most Gastropods. This has resulted in a great advance in eyes and other sense organs, and in brain. Further, the division of the foot into lobes ("arms") has provided them with a different type of organ from any other seen in other molluscs—a real set of limbs. Finally, most of them are fairly large; some indeed are gigantic, 30 feet or more across the outspread arms. These giants are for the most part inhabitants of deep water, whither they are pursued and attacked by the sperm whale. For all their complexity of organization, however, they are not a large or dominant group like the fish; something of the combined simplicity and efficiency of the fish is lacking in them, and they remain, like monuments of another type of civilization, to show the utmost that life was capable of producing along the Molluscan line of evolution.

The Brachiopods or lamp-shells are often mistaken for bivalve molluscs. In reality, they have quite another type of anatomy, with coiled tentacles instead of gills for the production of their food current. They are interesting because some of their species have persisted without the least visible change from the earliest fossil-bearing rocks till today. Evolutionary change is always occurring, especially among the latest products of evolution; but it is not a necessity. An animal may perform the same job in the world's economy for as long as the world is habitable.

The Echinoderms are a curious phylum. They are all marine and essentially bottom-livers, sometimes fixed by a stalk like the sea-lilies, more often capable of slow movement like the starfish, brittle-stars, sea-urchins, and sea-cucumbers. They are remarkable in being the only whole group of coelomates which have reverted from bilateral to radial symmetry. They are all five-rayed; but bear, in the form of a few small structures, unmistakable signs of an original bilaterality.

As would be expected, their sense organs are very poorly developed. Two very curious features may be noted. They move by means of a system of tube feet—a great number of little protrusible suckers filled

with water which can be made to adhere like a boy's "sucker" by the creation of a partial vacuum. And some of them, such as starfishes, sea-urchins, possess the oddest organs, called pedicellariæ, which every one who has a lens or microscope should examine when they are at the seaside. They are little stalked structures, each with three "jaws," and are continually moving from side to side making snapping movements, each one apparently quite on its own. It is probable that they help to defend the animal, and also to keep it from being overgrown with plants or sessile animals. Most Echinoderms have a larval stage, during which they are tiny transparent creatures, bilaterally symmetrical, swimming near the surface of the sea. It is clear that the Echinoderms represent the end of an evolutionary blind alley (Fig. 81).

CHAPTER THIRTEEN

THE ANIMAL KINGDOM (*contd.*): THE VERTEBRATES

FINALLY, THERE REMAIN the Chordates or Vertebrates. These claim our interest not only as the group of animals with the highest average attainment, not only as the group which contains our own evolutionary pedigree, but because a great deal of the detailed course of their evolution can be traced in the fossil-bearing rocks. All the invertebrate phyla and most of their classes had their origin so far back as to antedate the first fossil-bearing rocks we know. The earlier stratified rocks, that were laid down when they were first evolving, have been denuded away or so squeezed and baked through heat and pressure that their whole character has been altered, and the fossils they must have contained have been destroyed or rendered unrecognizable. Worms, echinoderms, arthropods, molluscs, corals, lamp-shells, many highly specialized and none essentially unlike those of today, are to be met with in the earliest well-preserved series of rocks, the Cambrian.

But with the vertebrates it is different. Probably their evolution took longer on account of their very complexity; in any case, the first vertebrates so far found belong to a primitive type of fish, and occur in the Ordovician, the next division above (more recent than) the Cambrian.

The main features of vertebrate evolution could be deduced equally well from comparative study of present-day forms, or from the anatomy and history of fossils. The two methods confirm each other in all essentials (Fig. 61).

Starting with fish, the salient steps in vertebrate evolution are as follows: (1) the partial conquest of the land by amphibians, involving the transformation of swim bladder to lungs, and of paired fins to true limbs with fingers and toes. (2) The full conquest of the land by reptiles, no longer restricted to dampness when adult or to water for their early development; this implied the evolution of a large-yolked egg, and the development of a protective water cushion or amnion

over the embryo within the egg. Instead of having to develop in water, each embryo is supplied with what an American writer calls "its own private pond" in the shape of the fluid within its amnion.

In higher reptiles (mostly now extinct and supplanted by mammals) the body was for the first time raised off the ground and supported entirely by the limbs (or with aid from the tail). Meanwhile, the heart became more or less completely divided into two separate parts, as in man, one for pumping venous and the other for pumping arterial blood only.

Two separate lines spring from the reptilian stock—the mammals and the birds. Both agree in having developed a mechanism for ensuring a constant temperature environment for the tissues of the body, and in having the heart completely divided into two. The first to be considered here (though the later to develop in evolutionary time) is (3) the bird line. The evolution of birds was made possible by a series of acquisitions. First, that of constant high temperature, next those of feathers, wings and air sacs. In addition, existing birds have lost their teeth, and bird parents show a remarkable degree of care for their young. These steps have led to the chief conquest of the air which has been made by vertebrates. (4) The other line led to the mammals. Apart from the constant high temperature and the divided heart, the two universal characters of mammals are the possession of hair, and the secretion of milk by the mother. Further, although a few mammals lay eggs, and a moderate number (most pouched mammals or Marsupials) bring their young up from an extremely early stage in their pouch, stuck firmly on to the nipples, yet the largest and the dominant sub-class of mammals are all characterized by a placenta or organ for ensuring interchange of food, respiratory gases, etc., between the mother and the embryo in the uterus, thus making possible not only a speedier development, but also the protection of the embryo within the mother until a later stage than occurs anywhere else in the animal kingdom. All typical mammals are also characterized by having a division of labour among their teeth (incisors, canines and grinders), which only occurs elsewhere in one extinct group of reptiles.

These different steps took place at different geological times. The chief facts are shown graphically in Fig. 82, which also indicates the

probable relationship of the main groups, and their relative importance at different periods.

One or two interesting points emerge. The fishes have continued their unabated success, as the most generally successful group of water-living animals, from very early times up till the present: they hardly compete with mammals or birds. But the amphibia had their

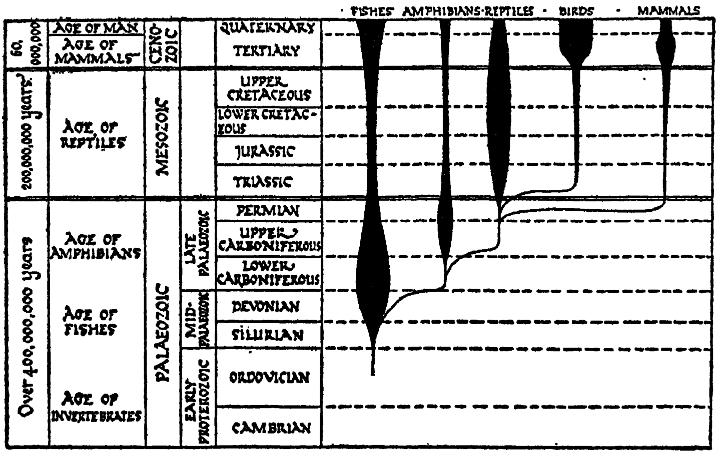


FIG. 82. Diagram to show the succession of the five main vertebrated classes in geological time. The approximate length in years (deduced from radio-active minerals) of the three main epochs is given on the left. The thickness of the black columns for each class represents roughly its abundance and dominance. (Probably those for fish and amphibians should not contract in the Mesozoic to less than their final thickness; and that for the reptiles should contract much more intensely at the close of the Mesozoic.) (Newman, *Vertebrate Zoology*, 1920.)

hey-day, and sank with the rise of reptiles; the reptiles had a still more marked and more remarkable period of dominance, ending with reptilian collapse and avian and mammalian advance, and the non-human mammals are now showing the same kind of decrease coincident with the rise of man. Thus in the fossil record a succession of types is really visible, and the succession is definitely one of lower by higher types.

There are, however, other Chordates beside these five classes. Space forbids mention of some of the doubtful "poor relations" of

the stock, and only allows the briefest reference to the Tunicates. These latter are a degenerate group which have lost many of their distinctively Chordate characters. Their degeneration, as in the

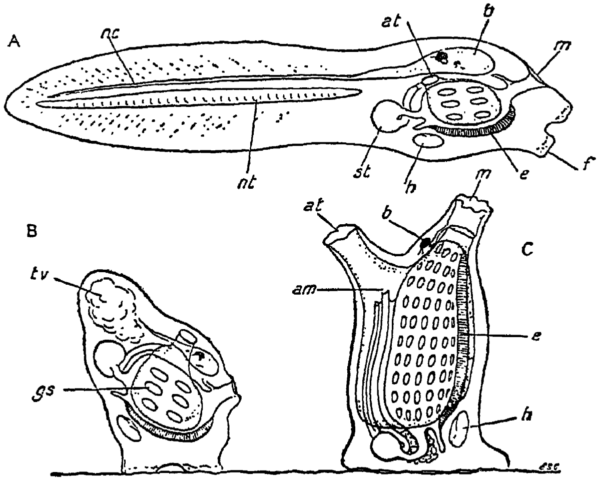


FIG. 83 (semi-diagrammatic). The metamorphosis of a sea squirt (*Ascidian*). (A) The free-swimming "tadpole" larva, with tubular nerve cord, *nc*, dilated anteriorly to form the "brain," *b*, with eye spot and balancing organ in its wall. Below it in the tail, *t*, is a well-developed notochord, *nt; m*, mouth, leading into pharynx perforated by gill-slits, with food-entangling mechanism, *e*, (endostyle). From the pharynx arises the gullet, leading into the stomach, *st*, and intestine; this opens into the mantle cavity, which in its turn opens to the exterior by the aperture, *at; f*, adhesive organ for fixation; *h*, heart. (B) The larva has fixed itself. The tail is degenerating, the mouth and internal organs are growing round; *gs*, gill-slits; *tv*, degenerating remains of tail. (C) Metamorphosis is complete. The animal is permanently fixed. Tail, notochord, nerve-tube and sense organs have disappeared. A solid ganglion, *b*, has been formed from the brain. The pharynx and atrium are much enlarged, and their apertures prolonged into siphons; *am*, anus.

bivalve molluscs, is due to their having adopted the method of feeding by producing currents and straining off the food particles; this has led to a sessile mode of life and to loss of sense organs and diminution of brain. Many of them form colonies by budding, and have surprising

powers of regeneration and dedifferentiation; they are hermaphrodite. They have also lost their skeleton; indeed, each one of them possesses it as a free-swimming larva, and loses it and all the main sense organs when it metamorphoses and settles down. They must have branched off, however, at a very early period from the main Chordate stem, and it is perhaps comforting to reflect that if they have lost their skeleton it was by then only a notochord and not a real backbone (Fig. 83).

A related form, but one much closer to the original primitive

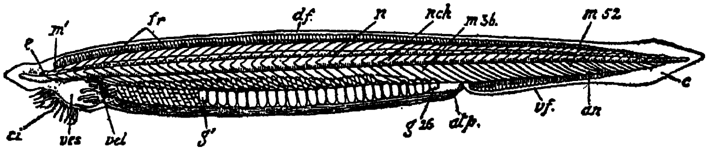


FIG. 84. A mature specimen of Amphioxus, from the left side. *an*, anus (not at the posterior extremity); *atp*, aperture of the cavity surrounding the pharynx (cf. sea squirts, Fig. 83); *c*, tail fin; *ci*, tentacles, acting as strainers, round the mouth; *df*, dorsal fin with crowded small fin rays, *fr*; *e*, eye spot on slightly dilated end of neural tube, *n*; g^1 to g^{26}, the 26 paired reproductive organs; m^1, m^{36}, m^{52}, the 1st, 36th and 52nd muscle segments (myotomes); *nch*, notochord running the whole length of the body, and thicker than the nerve-tube; *vel*, second straining organ, at entrance to pharynx; *ves*, mouth cavity; *vf*, ventral fin; the gill-slits are seen below the notochord from just behind *vel*, to the 31st muscle segment.

Chordate type, is seen in Amphioxus. The most important things about Amphioxus are those which it does not possess. It has nothing that could be called a head; the merest apology for brain and distance receptors; no skeleton except a notochord; no heart, but only an ordinary blood-vessel which contracts rhythmically, a liver which is a mere unbranched pocket of the gut, no limbs, no reproductive ducts, the eggs and sperm simply bursting out through the body wall. It is, however, without a question a Chordate, as shown by its notochord, its pharynx pierced by gill-slits, and its hollow nerve cord running along the back instead of the belly. It too depends on artificial currents for its food. It serves to remind us of a time long before that of the earliest fossils preserved to us now, when none of the Chordate stock had reached a higher organization than this; and all the highest

types of life—bird, horse, lion, dog and man himself—were no more than a potentiality slumbering in the germ cells of little Amphioxus-like creatures in the sea (Fig. 84).

The next stage in vertebrate evolution of which we have any record is represented by the Lampreys; but there is an enormous gap

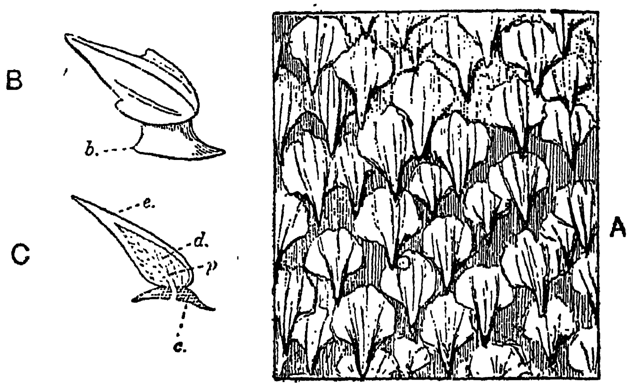


FIG. 85. Denticles of the dogfish. (A) A piece of skin, slightly magnified, in surface view; it is covered with denticles, their points projecting obliquely upwards. (B) A single denticle: *b*, the portion embedded in the skin. (C) A denticle in section: *c*, the embedded base, in the centre of which is an aperture by which blood-vessels and nerves enter *p*, the pulp cavity; *d*, dentine; *e*, enamel.

between them and Amphioxus. The lamprey has already a well-developed brain, a rudimentary skull and backbone of cartilage as well as a notochord, "nose," eyes and ears, and a proper vertebrate heart and liver. But they are still far behind any true fish. They have no limbs, no true jaws, no true teeth, and none of them have bone. They, too, like Amphioxus and its relatives, make but a very small group, a relic from the past.

In their life-history they shed a most interesting light on the evolution of the thyroid gland. The lampern, as the lamprey's larva is called, still obtains its food from a food current, in the same way as Amphioxus and the Tunicates. One of the special features of the straining mechanism of all these Chordates is a groove called the endostyle running along the floor of the pharynx, which secretes a

sticky mucus. This is forced forward by cilia, round the mouth in two grooves, and along the dorsal groove back into the intestine. The gill cilia are so arranged that all food particles strained off by the gills are driven up to the dorsal groove. Here they become entangled and stuck in the slime, and are passed on by this sort of moving staircase to be digested in the intestine.

The lampern has an endostyle just like that of Amphioxus, except that it is rolled up in a sort of pocket under the pharynx, and sends out its slime cord ready made.

When the lampern changes into the lamprey, most of the endostyle degenerates altogether. But some of the cells of its duct remain alive, multiply, and become converted into a typical thyroid. This is a transformation that nobody would have been rash enough to guess at, if they had not been able to see it actually happen, and it is of interest as showing the way in which one organ, no longer required by the animal, may become converted into another organ instead of disappearing altogether. This is frequently to be seen. The balancing planes—the paired fins—of fishes become supporting limbs in land forms; the swim bladder which regulates a fish's density and consequent distance from the surface becomes a breathing organ—the lung; hair in man has lost its primitive warmth-retaining function, and under the influences of sexual selection has become converted to an adornment.

A gap again yawns between the lamprey and the fish, although not such a wide one as that between Amphioxus and lamprey. No fish has a notochord persisting at full size throughout life; all have well-developed vertebræ and skull over-arching the brain, paired limbs, scales and teeth. The true jaws have appeared, and can be shown to have arisen by another strange change of function; they are derived from the first pair of the bars of cartilage which support the gills and hold the pharynx cavity stretched as an open umbrella is held out by its ribs. In almost all fish, however, the upper jaws are not yet firmly united to the skull as in all land forms, but only jointed on. Teeth, too, have an odd history. The skin of dogfishes and sharks can be used for polishing, and when prepared is known as shagreen. Its qualities are due to thousands of little pointed scales sticking out from its surface. When these are examined, each is seen to be nothing

else but a miniature tooth fixed by an enlarged base. Before teeth served as teeth they were scales, and covered the whole surface of the body. It was those in the skin covering the jaws which were able to take on new functions, became true teeth, and eventually alone remained when all traces of the skin-denticles had disappeared (Fig. 85).

There are two main groups of fish—the Elasmobranchs (dogfish, sharks, skates and rays), which have never developed bone in their

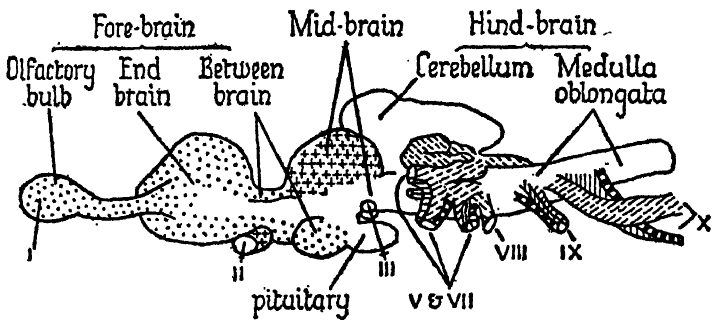


FIG. 86. The brain of a dogfish (*Squalus acanthias*), from the left side. The cranial nerves are marked with Roman numerals (IV and VI are not shown). The parts of the brain concerned with various senses are marked as follows: smell, coarse dots; sight, crosses; hearing, balance and lateral line organs, broken oblique lines; touch and other skin senses, vertical lines; taste and other stimuli from viscera (gills, stomach, etc.), horizontal lines. The motor nerves to gills, stomach and other viscera are marked in black and white rectangles.

skeleton, and the Teleosts or higher bony fish, comprising all the familiar species like herring, sole, trout, cod, sea-horse and flying-fish. The former are primitive in a great many ways. In one respect, however, they are better equipped than the Teleosts. They lay a few large-yolked eggs, well protected in horny capsules (the "Mermaids' Purses" one picks up on the seashore) or even in the oviduct of the mother; while the latter lay their eggs before fertilization, and have to produce vast quantities of them in order to compensate for the inevitable wastage during their tiny and unprotected early lives. It is probable that this one specialization enables the Elasmobranchs to compete not too unsuccessfully with the Teleosts. Their brain

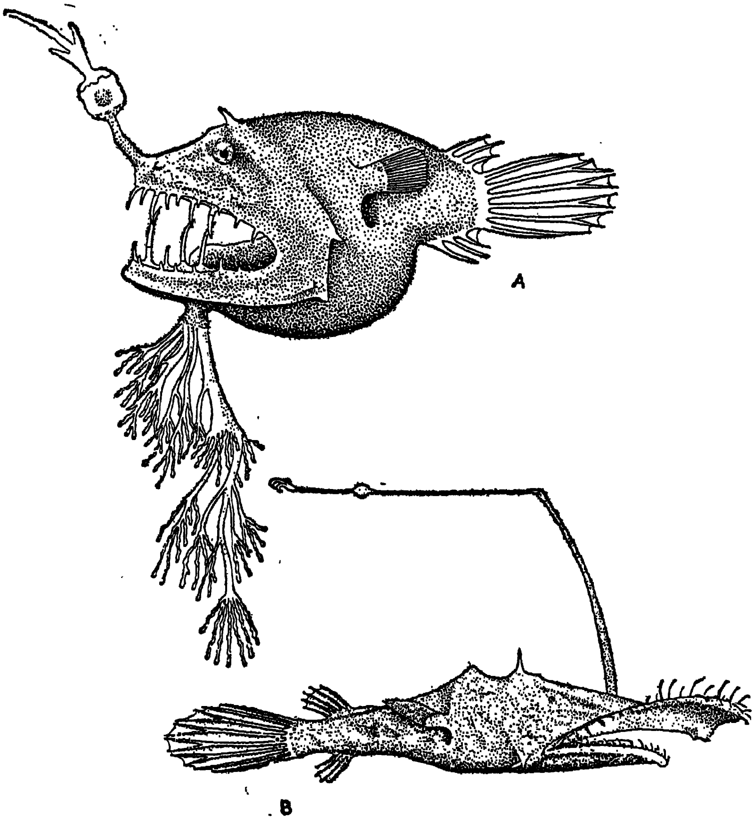


FIG. 87. Two deep-sea angler-fishes, to show their extraordinary structure and their adaptations to their mode of life: A. *Linophryne arborifer* (about 3 in. long; from 600 metres, in the Atlantic). The fish has a large luminous lure or bait on its snout, by means of which it attracts inquisitive animals to within snapping distance. The huge barbel on the lower jaw is probably tactile, like a cat's whiskers. B. *Lasiognathus saccostoma* (3 in. long; from 4,000 metres, in the Caribbean Sea). The luminous lure is here on a long, movable, jointed stalk, which terminates in three hooks. Apparently the whole apparatus is used like a baited rod and line. The mouth is fringed with long bristle-like teeth, which prevent the escape of the prey (probably Pteropods or Crustacea).

(Fig. 86) is very primitive, even when compared with that of the frog.

The smallest fish are under an inch in length, the largest is a form of shark which may reach 40 feet.

Fish have evolved into the most extraordinary forms. One could write a whole chapter on "Funny Fish"—pipe-fish, sea-horses, ribbon-fish, sun-fish without a proper tail, cow-fish, flying-fish, parrot-fish, porcupine-fish, electric-fish, the flat-fish which fall over on one side as they grow and twist both eyes over on to one side of the head, the remora with a sucker on its head to attach itself to its living locomotive the shark, angler-fish, deep-sea fish with eyes on long movable stalks, or with mouth as big as the whole body, or with rows of red and white phosphorescent lights like a liner at sea. Fish are the dominant group in the waters, and have become specialized to fill every available niche (Fig. 87).

One group of freshwater fish, the lung fishes, are able to survive a long sojourn in the mud when the ponds and streams dry up. This they do by extracting oxygen from the air taken into their swim-bladder, which thus acts as a lung when needed. Thus, these creatures partly bridge the gap to terrestrial life (Fig. 88).

In the structure of the limbs, however, a great gap exists between fish and amphibians. No fish has anything but fins, no amphibian anything but legs equipped with fingers and toes. Again, just as the thyroid gland was evolved from the remains of the endostyle when this ceased to be of use, so another ductless gland, the parathyroid, is not found in fish, but only arises out of the debris of the gill-slits when the vertebrates took to land.

The Amphibia need not detain us long. They are in a certain sense a compromise between life in water and life on land. The biggest existing amphibian is the giant salamander, which may reach 4 feet, though the Amphibia as a group average 6 inches or less. However, in the Carboniferous period, when they were the only land vertebrates, the average was much higher, and forms over 6 feet long existed; but all these disappeared as soon as the reptiles entered the field. One other point deserves mention. The Amphibia are the first vertebrates capable of producing vocal sounds deliberately.

The reptiles were the true conquerors of the land. This conquest they owe chiefly to their dry, strong skin, and the evolution of special

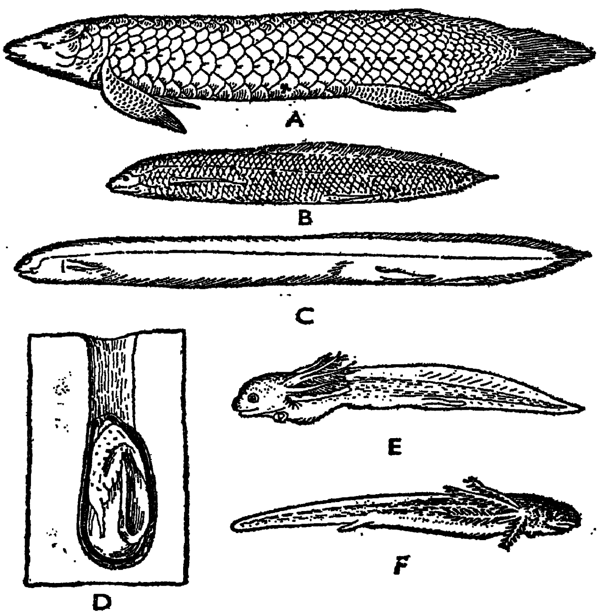


FIG. 88. Various lung fishes (*Dipnoi*). (A) Ceratodus, with well-developed fins, from Queensland. (B and C) Protopterus and Lepidosiren, from tropical Africa and South America respectively, with reduced fins. In all, note the absence of streamlining in the body and the wide separation of fore- and hind-limbs. (D) Protopterus æstivating in a burrow in mud in the dry season. It has enclosed itself in a flask-shaped membrane of slime which has hardened on drying, and has an aperture for air leading into the mouth. Between this membrane and the fish's body is a layer of soft slime (mucus). (E and F) Larvæ of Protopterus and of Lepidosiren, seven and thirty days after hatching respectively. Note the well-developed external gills and the general resemblance to the tadpole of a tailed amphibian. The rudiments of the limbs are presented as long cylindrical outgrowths. (Newman, *Vertebrate Zoology*, 1920.)

membranes helping the embryo to live away from water in a large-yolked egg. The allantois, from which the placenta afterwards developed, is the embryo's breathing organ: the amnion is a protective water cushion, enabling the soft embryo to develop in fluid, protected from pressure and contact (Plates 10, 11).

In their hey-day the reptiles rivalled the present mammals in size and variety of specialization. Besides the existing lizards, snakes, crocodiles and tortoises, there lived in the middle and late Secondary period a whole series of remarkable types. There were mammal-like reptiles, equipped with several different kinds of teeth, and able to run like a typical quadruped; flying pterodactyls (Fig. 89); at least two types which had gone back to the sea, the ichthyosaurs, which more or less resembled whales (and produced their young alive, as a specimen in the South Kensington Museum testifies, with a brood of embryo skeletons between its ribs), and plesiosaurs, with great flexible necks, creatures which must have looked very much like the average man's idea of the sea serpent; and, finally, the most successful group of all, the dinosaurs, including rapid runners on two legs, living "tanks" covered with armour-plate, great semi-aquatic herbivores like Diplodocus (Plates 20 (iii), 21), some of which grew to a hundred feet long, and the biggest carnivorous creatures ever known, such as the Tyrannosaurus, which stood over 20 feet high, and no doubt lived upon the gigantic vegetarians.

The end of the Secondary period comes, and with the beginning of the Tertiary the pride of the reptiles is humbled. More than half the groups, and those the most advanced, no longer exist; those that are left are already playing second fiddle to the early mammals and birds.

What brought about this revolution is not certain. Possibly an alteration of climate cut down the available food supply and gave advantages to smaller creatures capable of temperature regulation. There can at least be no doubt that temperature regulation and better provision for the young, both before and after birth or hatching, are the two progressive features in which birds and mammals chiefly outdistance their ancestors, the reptiles.

In the case of birds, we luckily have come to possess true "missing links" between reptiles and modern birds. In the mid-Secondary,

there lived a creature called Archæopteryx—"earliest winged creature." It was an undoubted bird, for it possessed feathers and obvious wings. But its jaws possess a good complement of teeth, the wing is still extremely primitive in possessing claws on three of its fingers (by means of which it no doubt crawled like a bat among the branches), and its tail is not a fan as in all living birds, but is more like that of a kite, with a long jointed skeleton, and feathers branching off on either side all the way down (Fig. 89).

Fossil birds found in strata from the close of the Secondary already possessed the modern fan-like tail, and had lost the claws on the wing; but they all still possessed teeth. Toothless birds only appear with the Tertiary period.

Flight, high temperature (over 100°, sometimes as much as 105° Fahrenheit), air sacs and hollow bones, nest-building, bright colours and elaborate courtship, song, and the care of the young—these are the chief characters of modern birds. They owe their success chiefly to one single character—the evolution of feathers. These in the first place keep down radiation and so allow of a high body-temperature. They also permit of the fore-limbs alone being used in flight. Thus the hind-limbs are left free to develop along their own lines, instead of being used up, so to speak, as one of the supports for a wing membrane, as occurred in the extinct flying lizards, and occurs today in the bats. The air-sacs not only lighten the body and help in breathing, but are used to streamline the body so that it offers least possible resistance to rapid passage through the air. In the same way, most of the fuselage of an aeroplane only serves for streamlining, not for carrying passengers or goods.

Birds are on the average notably smaller than mammals. This is due to purely mechanical aeronautical limitations too complicated to discuss here; as a matter of hard fact, the largest birds capable of flight—swans, vultures or albatrosses—weigh well under 50 kilograms, while the weight of the great majority is to be reckoned in ounces or even grams, the smallest humming-birds weighing a little under 2 grams.

It is interesting to compare the success of reptiles, birds, and mammals in different zones of the earth's surface. Reptiles have the temperature of their surroundings; consequently their activity is

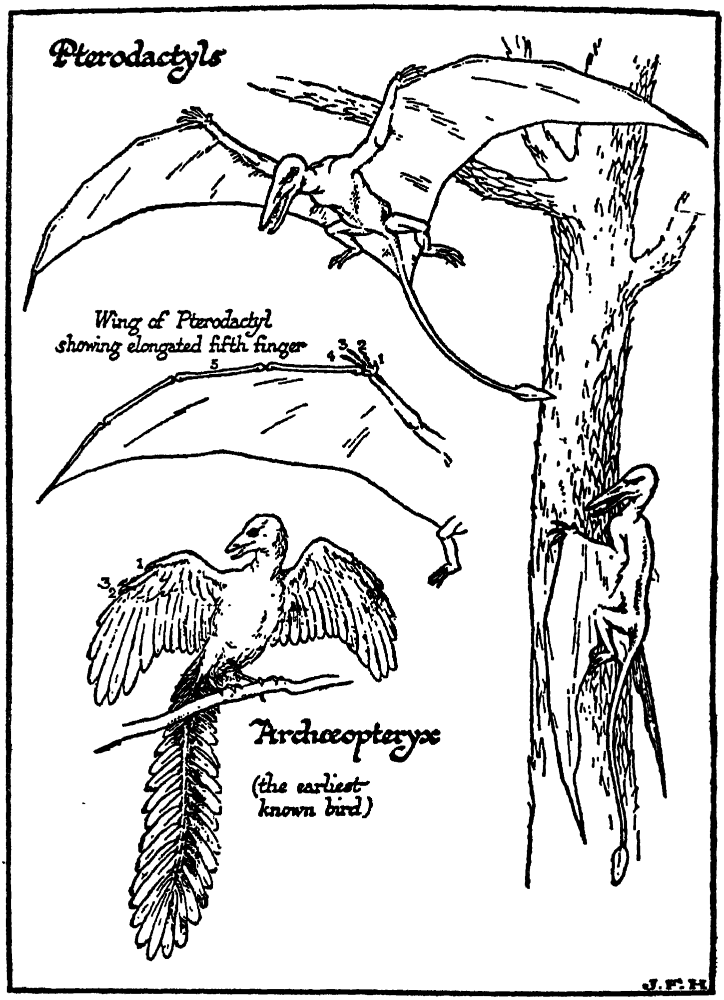


FIG. 89. Restorations of flying reptiles (*Pterodactyls*) and the primitive bird *Archæopteryx*. The Pterodactyls had membranous wings like bats, supported both by fore- and hind-limbs, but mainly by the "little" finger. The remaining fingers could still be used as claws. Archæopteryx had true feathers, and wings supported only by the fore-limb, but it retained teeth, a long tail skeleton feathered on either side instead of the tail fan of modern birds, and three clawed fingers.

somewhat more than doubled for each rise of 10° centigrade. In the Arctic they could scarcely ever be active at all, but would have to exist in a state of almost continuous hibernation, and there are in point of fact no reptiles in the Arctic. In the temperate zone they must waste half their life hibernating, and even in the summer cannot compete in activity with a warm-blooded creature; so here reptiles are few and small. In the Tropics, however, their average speed of living is more nearly that of a mammal, and they can be active all the year round; in the Tropics, therefore, reptiles are more abundant and of greater size—crocodiles, iguanas and other large lizards, giant

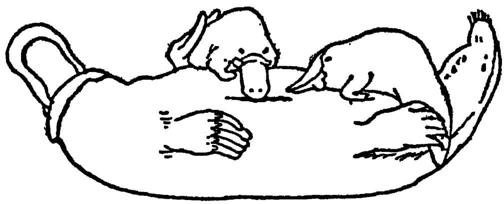


FIG. 90. A female duck-bill platypus (*Ornithorhynchus*) suckling its young. The young are hatched from eggs. The mother has milk, but no teats; she therefore lies on her back, and the young lap up the milk from the saucer-shaped depression into which the milk glands open. The mother is supporting one young with her left fore-foot. (Newman, *Vertebrate Zoology*, 1920.)

turtles and tortoises, boa-constrictors and pythons are all tropical (Plate 22).

Mammals, owing to merely mechanical reasons, can attain to larger sizes than birds. On the other hand, they cannot move readily from one zone to another. So it comes about that in the Arctic the birds are the dominant vertebrates, because they can leave in the winter; Arctic mammals are few, and almost all of them (like seal, walrus, polar bear and whale) are entirely or chiefly aquatic. The mammals on the other hand are the dominant group in temperate and sub-tropical regions.

There are one or two points in connexion with the evolution of mammals that are worth mentioning here.

What feathers have been to birds, hair has in part been to

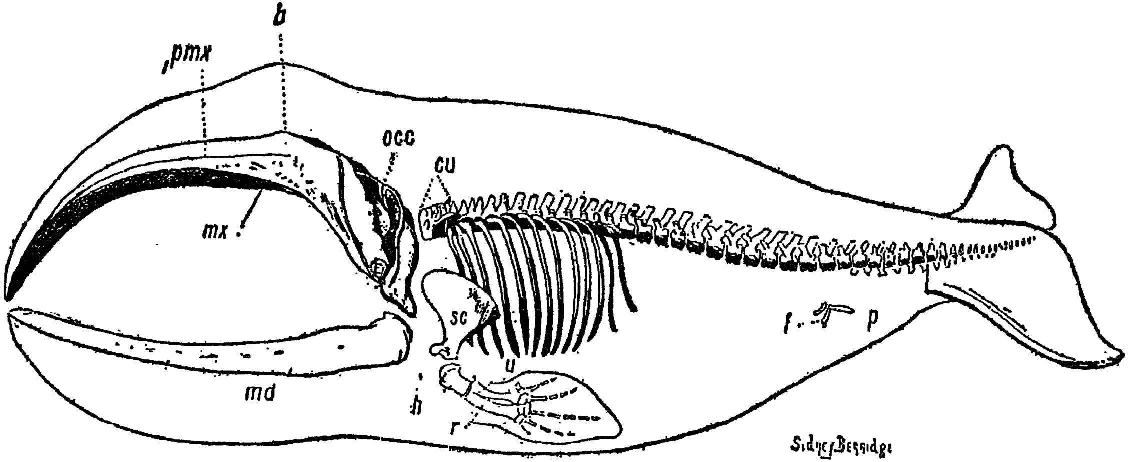


FIG. 91. Outline and skeleton of a right whale (one of the whalebone whales). Note the enormous enlargement of the jaws (*pmx*, *mx* and *md*) for the attachment of the straining apparatus of "whalebone"; the fore-limb converted into a paddle (*sc*, shoulder-blade; *h*, humerus; *r*, radius; *u*, ulna); the vestigial hind-limb and girdle embedded in the flank (*p*, pelvis; *f*, femur; the other parts of its skeleton have disappeared); the reduction of the neck (the seven neck-vertebræ, *cu*, are fused into one bone); the fish-like shape and the tail placed horizontally for rapid diving. (From Natural History Museum *Guide*.)

mammals; hair and milk together are the mammalian characteristics *par excellence*, hair permitting a constant temperature, milk implying a long period of care of the young after birth. Hair and milk have given mammals the victory over reptiles. But within the mammalian stock itself progress has depended chiefly on two other factors—brain and pre-natal care.

There are three grades of pre-natal care to be found in the single class of mammals. The duck-bill platypus (Fig. 90) and echidna lay eggs like any reptile. The Marsupials, such as the kangaroo and opossum, nourish their young within their uterus; but the mechanism is not elaborate enough to permit of its being effective after the embryo has grown to a comparatively small size. To meet this difficulty, the pouch has been evolved. The embryo is born very small and very unformed (a new-born kangaroo is less than 2 inches long, naked and blind, the limbs not yet provided with fingers). It can, however, crawl into the pouch; there it becomes glued to the nipple until it reaches a stage more or less similar to that at which higher mammals are born, then becoming detached, but still spending its time in the pouch.

The typical or Placental mammals, on the other hand, while still retaining the milk diet for their young after birth, all possess the wonderful arrangement known as the placenta, by means of which a huge network of blood-vessels formed by the embryo interlocks in the wall of the uterus with a similar network formed by the mother. By this means, although there is no actual passage of blood from mother to embryo, perfect interchange and nutrition is provided, and the embryo can be protected until fully formed. In some whales the young are retained within the mother's body till they are over 20 feet long. Whales, being aquatic, can attain to much greater size than any terrestrial animal. They include by far the largest animals which have ever existed, at least twice the bulk of the largest extinct reptiles. They also show interesting traces of their origin from land forms in vestigial hind-limbs (Figs. 91, 92).

The Placentals have become as dominant over the Marsupials, wherever the two groups have come into contact, as the mammals over the reptiles. Only in Australia, which was cut off from the rest of the world by some earth movement after it had received

an invasion of Marsupials but before it had been reached by any Placentals, are the Marsupials dominant—because without placental competitors.

It is very interesting to find that the Australian Marsupials have evolved into a great many forms not found elsewhere, whether fossil or alive, and that the types evolved are often superficially very similar to those of Placental mammals. There is a marsupial wolf, a marsupial mole, the wombat is like a cross between a badger and a bear, some of the phalangers are not unlike squirrels.

The kangaroo, it is true, is of very different construction from any

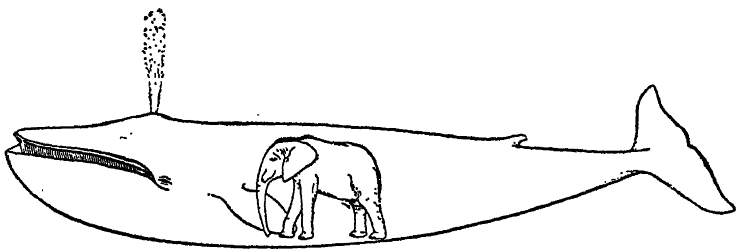


FIG. 92. Sulphur-bottom whale (*Balænoptera sulphureus*), 87 feet long, with the African elephant "Jumbo" (*Loxodonta africana*), 11½ feet high, drawn to scale. (Lull, *Organic Evolution*, 1922.)

large Placental. It has filled the niche of herbivorous quick-moving animal, but has filled it in a different way from horse or deer.

There are, in fact, the same niches to be filled the world over, and different types may fill them in ways superficially alike or superficially different.

Then there is brain. This has played its chief role in the intense competition which took place in the Placentals. Throughout the Tertiary period new lines of evolution were being developed with great rapidity. The upper limit of size was being increased (as, for instance, in the evolution of the horses, the elephants, the whales, the great cats), and physical specialization, especially of teeth and limbs, was being perfected. Both size and physical specialization, however, soon reached a limit. The supporting power of a limb bone is proportional to its cross-section, i.e., to an area; while the weight to be supported varies as the volume. For purely mechanical reasons,

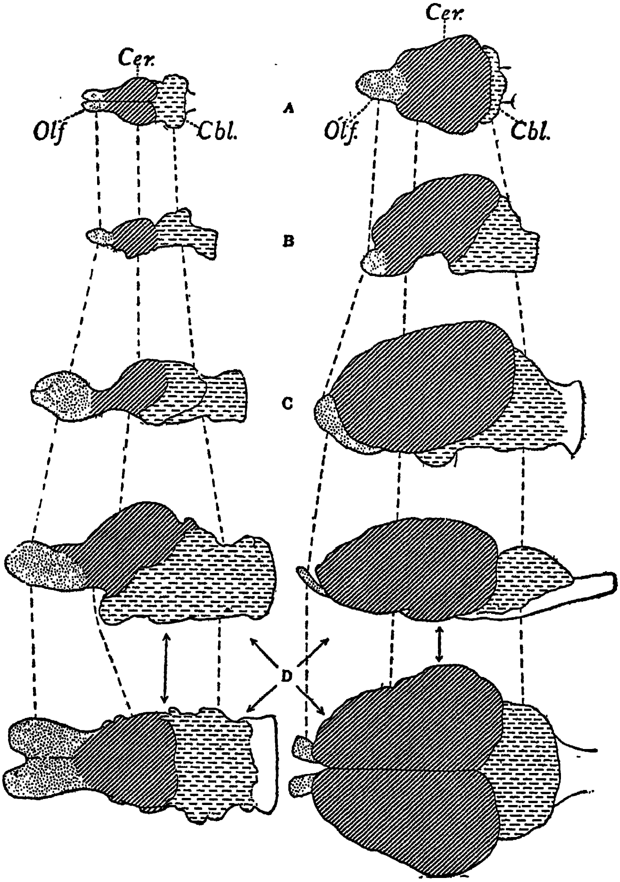


FIG. 93. To illustrate the increase in relative size of brain during the evolution of the mammals. The brains on the left (reconstructed from casts of the interior of the skull) are those of mammals from the early Tertiary period. Those on the right are those of living mammals of about the same total bulk. The two brains of each pair are drawn to the same scale.

Arctocyon (a primitive carnivorous form)	A	Dog
Phenacodus (a primitive ungulate form)	B	Pig
Coryphodon (an extinct heavy herbivorous type)	C	Rhinoceros
Uintatherium (related to Coryphodon)	D	Hippopotamus

The modern brains, in addition to their increase in absolute size, show an alteration of proportions, the olfactory lobes being relatively rather smaller, the cerebral hemispheres relatively much larger.

therefore, the limb bones must become relatively larger with increasing absolute size until they finally grow so unwieldy that size no longer pays. A rhinoceros or an elephant is near the upper margin of size mechanically permissible with advantage to a land animal. As regards specialization, the leg and foot of a horse or a deer, or the teeth of a lion or a cow, could not be much better adapted to their functions than they are now.

But, if the instruments at the animal's disposal could not be improved, the methods of using them might be—and this is possible by an improvement in the structure of the brain. The figure on p. 373 may be left to speak for itself (Fig. 93).

The final changes which led to man's evolution seem also to have been primarily brain changes (Fig. 94). Probably, the first divergence of the future human stock from the ordinary land-living mammals came when some shrew-like insect-eating animal took to living in trees. From some creature like this the lemur type probably developed, from this again the monkey type. From the old world monkeys the true apes have clearly descended, by loss of tail and increase of brain power, and there is no doubt that from some creature which, though not any of the existing apes we know, would have to be classified in the same group with them, man finally evolved. True apes, like the chimpanzee, are very intelligent and educable (Plate 23).

Taking to the trees appears to have been the necessary preliminary to this long evolution. This put a premium on accurate vision and movements which had to be complicated and accurate if the creature was not to fall and lose its life, while the ordinary land mammals continued utilizing smell more than sight, and turning their limbs into mere supports and running organs.

Only in the trees will there grow up the practice of handling objects carefully, and checking the results by careful examination with the eyes, and this eventually led to the development of a true hand and to the manual skill of human beings. It is interesting to find that the parts of the brain connected with sight and manual dexterity increase in size as we pass from lemurs up through apes to man, while the centres connected with smell decrease very much in relative importance (Fig. 94).

But physical acquisitions react upon the mind. The monkey has

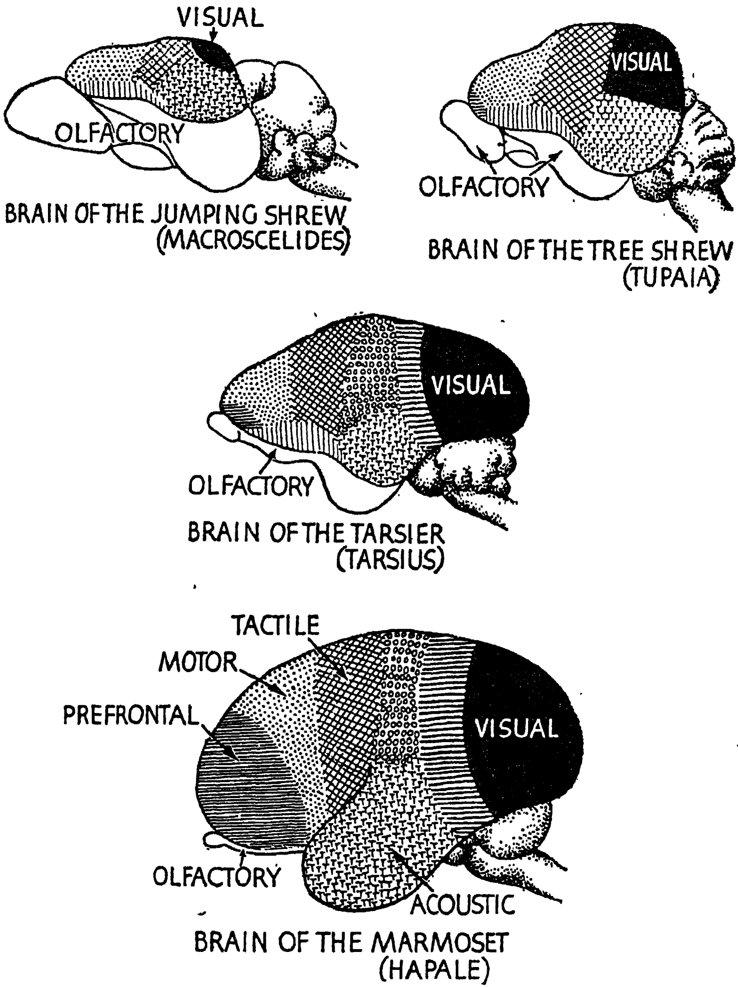


FIG. 94. Development of the brain and its different regions in animals on various levels of development not unlike those which man's ancestry traversed. (*Above*) Two Insectivores. Note the much greater development of the visual region and reduction of the olfactory region in the arboreal tree-shrew as compared with the terrestrial jumping shrew. (*Centre*) The tarsier, the lemur nearest to the monkeys. (*Below*) One of the most primitive true monkeys. The same tendencies are continued and accentuated. In addition, note the enlargement of the pre-frontal area serving for association.

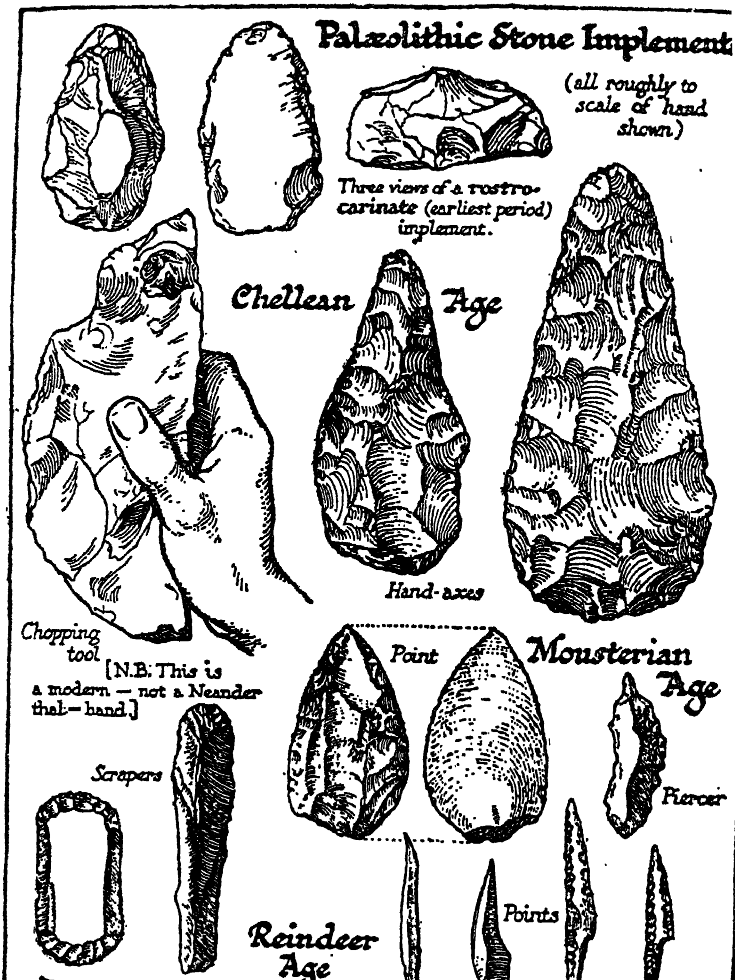


FIG. 95. Various Eolithic and Palæolithic flint implements, showing different types used for different purposes, and various degrees of shaping and finish.

power of examining an object accurately by touch and sight. As is always the case, it is pleasant to indulge a power that we possess; and hence, it appears, the development of that extraordinary curiosity we all know in monkeys. Their curiosity is largely aimless and useless,

but if it could be harnessed to the needs of the race, it might yield the most valuable results, and as a matter of fact this curiosity was the necessary basis of all man's philosophy and science.

Man himself in all probability developed in some temperate and comparatively treeless region, where the surroundings forced him down out of the easy retreat afforded by the tree tops, and compelled the development of skill, foresight and reasoning power to cope with the animals that were his enemies and those which, in the absence of fruits, he would have to use for food. The rest of the ape stock remained in its tropical forest home and was never forced to develop further. Remains of a real link between apes and men, the Pithecanthropus, have been found in Java. In the earlier period of human existence, several species of man, some definitely more simian than any types known today, were evolved (Plate 24). But today only one species survives.

Man probably originated in the Pliocene. To discuss the detailed development of man is outside the scope of this book. We may mention that prehistoric man is known chiefly by the stone implements which he has left behind (Fig. 95); in these a slow but gradually accelerated progress is found with the passage of time (Fig. 96). He had to survive the Glacial period, an unfavourable environment which probably served to sharpen his wits; and only about ten thousand years ago at the utmost did he discover the use of metals or the methods of regular agriculture.

In conclusion, since inevitably our interest will centre on the biology of man, we will end this chapter by recapitulating what we have learned of evolution with special reference to those steps without which human development would have been impossible.

After the development of the cell, and the origin of sex (which made variation easier when needed), the first necessary step was the aggregation of cells to form many-celled organisms; without this, neither convenient size nor sufficient division of labour would have been possible. The next steps were precisely those of increasing total size and increasing division of labour among the organs.

First came the establishment of two and then three main layers with different functions, and at the same time the increasing importance of the head end, due to bilaterality and the formation of a

nervous-system with a dominating region or primitive brain in front. The development of blood-system and cœlom obviated the need for branched organs, and made much greater size possible. Segmentation again increased the possibilities of division of labour. Increased size made necessary special organs such as heart and gills, while more rapid locomotion was only possible if better sense organs

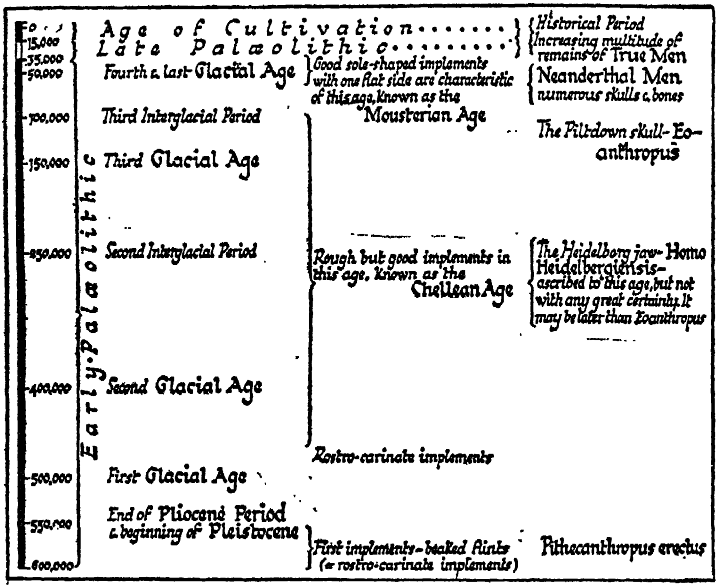


FIG. 96. Diagram to show the probable history of man, as revealed by fossils and implements, from the end of the Pliocene. An approximate time-scale in years is on the left. Note the enormous length of the primitive Palæolithic culture as compared with all subsequent cultures (Neolithic, Copper, Bronze and Iron Ages, and historical period).

and better nervous co-ordination was brought about. Ductless glands made possible a new chemical co-ordination, especially valuable in regulating growth.

Then the emergence from water to land provided a new freedom; temperature regulation made life stable and was an absolute necessity for any delicately adjusted mental life. The development of a complicated brain with emotional moods controlling action, made courtship necessary between the sexes; and out of this has developed much

of our sense of beauty. The need to develop out of water produced the reptilian egg; and the further prevention of waste of infant life was brought about by the internal development of mammals, permitting the young organism to come into the world at a greater size. As the mechanical efficiency of the organs of the body approached perfection, an increasing premium was put upon more efficient ways of using the organs—in other words, upon brain power. The most important development in this respect was improved power of learning by experience. But to learn by experience, the youth of the species must be protected and sheltered; hence the extension of parental care to the young for ever longer periods after birth, and the co-operation of both male and female parent in these duties. Out of this sprang the family, and the constant association on a common task doubtless made the need for communication more urgent, and so was a necessary step towards speech. Then came arboreal life, and the development of dexterity of movement, of the examination of objects by touch and sight, and so of curiosity. Then the re-descent to the ground, with necessity for great self-reliance and skill, and the harnessing of curiosity to be the basis of organized knowledge; with necessity too for more co-operation, and hence of speech, through which alone organized society became possible.

This brief sketch will perhaps give some idea of the strange series of processes, many of them apparently unconnected, which have yet been necessary for human beings to arise, and for mental activity to become the controlling factor in evolution.

In conclusion, it should never be forgotten that man is, biologically speaking, quite young. The half-million or million years for which he has been in existence constitute but a small fraction of the time which the non-human mammals, for example, took to reach their highest perfection.

GLOSSARY

ACTIVATION, exciting to action; especially, exciting the egg to begin its development.

ADRENAL BODY (L. *ad*, near; *ren*, kidney), a ductless gland attached (in mammals) near the top of each kidney, derived partly (the medulla) from cells migrated from the neural crest, and partly (the cortex) from cells closely allied to those from which the reproductive system is formed. ADRENALINE, the secretion from the medulla. Also called SUPRARENAL CAPSULE.

AFFERENT (L. *ad*, towards; *fero*, I carry), carrying towards; e.g., afferent (sensory) nerves carry impulses to the central nervous system.

ALBINO (L. *albus*, white), an organism with congenital lack of pigment.

ALLANTOIS (Gr. ἀλλᾶς, sausage; εἶδος, form), a sac-like membranous organ growing out of the hind-gut in the embryos of reptiles, birds and mammals, and serving for respiration or nutrition, or both.

ALLELOMORPH (Gr. ἀλλήλων, one another; μορφή, form) one of the alternative forms in which a single hereditary factor (gene) may exist.

ALVEOLAR AIR (L. *alveolus*, little trough: small air-sacs in the lungs), air in alveoli of the lungs, where gaseous exchange with the blood is effected.

AMNION (Gr. ἀμνίον, bowl), a membranous sac containing fluid, which encloses the embryos of reptiles, birds, and mammals (hence called AMNIOTA).

AMPHIBIAN (Gr. ἀμφί, both; βίος, life), animals capable of living both on land and in water.

ANATOMY (Gr. ἀνά, up; τέμνω, I cut), the science of bodily structure, particularly as learnt from dissection.

ANTIBODY (Gr. ἀντί, opposed to), a substance formed as a reaction and defence against foreign proteins.

ANTITOXIN (Gr. ἀντί, opposed to; τοξικον, poison), a kind of antibody, produced as a reaction against certain types of poisons.

ARTERY (Gr. ἀήρ, air; τηρέω, I keep), vessels which convey blood away from the heart to the organs, etc.; most arterial blood is bright red as a result of being purified in the lungs, gills, etc. (The derivation recalls the mistaken belief of the early anatomists that the arteries contained air).

ASEXUAL REPRODUCTION, reproduction without sexual process; e.g., budding, fission.

AUTONOMIC NERVOUS SYSTEM, that part of the nervous system which controls glands and unstriped (involuntary) muscles, and the heart. It comprises the sympathetic and the parasympathetic systems (q. v.).

AXON (Gr. ἄξων, axis), the main outgrowth of a neuron (q. v.); axons constitute the essential portions of nerve-fibres.

BACTERIA (singular, BACTERIUM), (Gr. βακτήριον, little stick), extremely small single-celled plants, related to Fungi.

BILE (L. *bilis*, bile), a thick, complex fluid, secreted by the liver, which aids in digesting fats.

BIOMETRY (Gr. βίος, life; μέτρον, measure), the application of mathematical computation to life-processes, especially as regards variation and heredity.

BLASTOMERE (Gr. βλαστός, embryo; μέρος, part), one of the cells produced as the result of the segmentation of the fertilized egg.

BLASTOPORE (Gr. βλαστός, embryo; πόρος, passage), the external opening of a GASTRULA (q. v.), leading into the primitive gut.

BLASTULA (Gr. βλαστός, germ), the stage at the close of segmentation, in the development of multicellular animals, when the embryo is a hollow sphere, with no opening.

CALORIE (L. *calor*, heat), a unit of heat. SMALL CALORIE, the amount of heat required to raise the temperature of one gram of water from 15° C. to 16° C. LARGE CALORIE or KILOCALORIE, the amount of heat to raise the temperature of one kilogram of water through the same interval.

CAPILLARIES (L. *capillus*, hair), minute blood-vessels joining the ends of the arteries to the beginnings of the veins, with walls thin enough to permit the diffusion of soluble substances.

CHITIN (Gr. χιτών, a coat of mail), a horn-like substance secreted by Arthropods and some other animals as an external skeleton.

CHLOROPHYLL (Gr. χλωρός, green; φυλλον, leaf), the green substance which gives green plants their characteristic colour and enables them to utilize sunlight in building up their food.

CHORDATE, an animal possessing notochord. Chordates include Vertebrates (q.v.), Tunicates, Amphioxus, and a few other forms.

CHROMATIN (Gr. χρῶμα, colour), a constituent of the nucleus which stains very readily, and probably includes the hereditary constitution.

CHROMOSOME (Gr. χρῶμα, colour; σῶμα, body), deeply staining portions of CHROMATIN (q.v.), of definite number in each species, which are formed preparatory to nuclear division, and are longitudinally divided during the process. The bearers of the hereditary factors or genes.

CILIA (L. *cilium*, eyelash), numerous microscopic hair-like projections borne on the surface of some cells, which are capable of rapid, co-ordinated movements. (See FLAGELLUM.)

CLOACA (L. *cloaca*, a sewer), a cavity in some animals into which the intestine, excretory ducts, and reproductive ducts discharge.

COELOM (Gr. κοιλία, the belly), the main body-cavity in which the gut is usually suspended. It contains a colourless fluid.

CONVERGENCE (L. *con*, together; *vergo*, incline), the evolution of similar form or structure in unrelated organisms, as the result of a similar mode of life, and not as the result of inheritance from common ancestors.

CORPUSCLE (L. *corpusculum*, little body), a name given to some cells, such as blood corpuscles. (See p. 187 *et seq.*)

CYTOPLASM (Gr. κύτος, vessel), the protoplasm of a cell, excluding the nucleus.

DEDIFFERENTIATION, the process whereby specialized cells or tissues lose their characteristics, and become simple (undifferentiated).

DOMINANT. When one form (allelomorph) of a hereditary factor masks the effects of another form of the same factor, when both are present together, the first is called dominant, the second recessive.

ECTODERM (Gr. ἐκτός, outside; δέρμα, skin), the outer of the GERM-LAYERS (q.v.) produced in early development. From it, in higher forms, are produced epidermis and its products such as hair and feathers, skeleton of Arthropods, etc.; the nervous system, sense-organs; and nephridial excretory organs when present.

EFFECTOR (L. *efficere*, to accomplish), organs whose function it is to liberate energy or produce material on behalf of the organism—e.g. muscles, glands, electric and phosphorescent organs.

EFFERENT (L. *ex*, out; *fero*, I carry), carrying away from: e.g. efferent (or motor) nerves carry impulses outwards from the central nervous system.

ENDOCRINE SYSTEM (Gr. ἔνδον, within; κρίνειν, to separate), all the tissues of internal secretion; the ductless glands.

ENDODERM (Gr. ἔνδον, within; δέρμα, skin, membrane), the inner of the GERM-LAYERS (q.v.) produced in Metazoa during early development. From it, in higher forms, are produced the lining of the gut and of the digestive glands, and, in vertebrates, the lungs, most of the lining of the gill-slits, thyroid, thymus and parathyroid.

ENDOSTYLE (Gr. ἔνδον, within; στῦλος, pillar), a ciliated glandular groove in the floor of the pharynx of Amphioxus, where mucus is formed in which food is entangled. The thyroid gland of higher Vertebrates is derived from this.

ENZYME (Gr. ἐν, in; ζύμη, leaven), one of a group of substances in the body which bring about, or speed up, a particular chemical reaction.

EPIPHYSIS (Gr. ἐπίφυσις,), the bony disk or pad, derived from a separate centre of ossification, found at either extremity of limb bones and vertebrae. At maturity, the epiphyses become fused with the main body of the bone.

EPITHELIUM (Gr. ἐπί, upon; θηλή, teat), a sheet of tissue, one or more cell-layers thick, covering or lining a surface.

ERYTHROCYTE (Gr. ἐρυθρός, red; κύτος, cell), a red blood-corpuscle.

EXCRETION (L. *excretus*, separated out), the process by which waste products are removed from the body.

EXTENSOR (L. *extendo*, I stretch out), a muscle or muscles that straighten a joint.

EXTEROCEPTOR (L. *exter*, outside; *capĕre*, to take), receptor organs affected by changes outside the body.

FACTORS, of Heredity. (See GENE.)

FAECES (L. grounds), the unutilized residue of the food in the gut.

FLAGELLUM (L. whip), a minute external whip-like process of certain cells, capable of active movement. When such processes are small and numerous, they are called CILIA (q.v.); if few, or single, flagella.

FLEXOR (L. *flecto*, I bend), muscles that bend a joint.

GAMETE (Gr. γαμέτης, spouse), one of the cells which unite at fertilization to form a zygote. Gametes are usually distinguishable into male and female.

GANGLION (Gr. γαγγλιον, swelling), an aggregation of nerve cell-bodies.

GASTRULA (Gr. γαστήρ, belly), the stage of development in multicellular animals when the embryo is a two-layered sac surrounding the primitive gut, with one opening, the blastopore.

GENE (Gr. γένος, origin), the Mendelian units in the germ plasm which control the appearance of definite characters in the offspring: hereditary factors which segregate according to Mendelian principles.

GERM-CELL. A reproductive cell, or one which will give rise to reproductive cells: a cell which is not somatic. (See SOMA.)

GERM-LAYER. One of the fundamental two, or three, layers of cells which appear early in the development of multicellular animals. All multicellular animals have two, ectoderm and endoderm; most groups have also mesoderm.

GERM-PLASM. The sum of the hereditary factors; that part of the organism which is transmitted to its descendants in reproduction.

GLAND (L. *glans*, nut), an organ whose chief function it is to secrete or excrete some special substance.

GONAD (Gr. γόνος, reproduction), an organ of sexual reproduction (ovary or testis).

HAEMOGLOBIN (Gr. αἷμα, blood; L. *globus*, a round, hence *globulin*, a proteid), the red colouring matter in blood, concerned with the transport of oxygen.

HERMAPHRODITE (Gr. Ἑρμῆς, the god Hermes; Ἀφροδίτη, the goddess Aphrodite), having both male and female reproductive organs.

HISTOLOGY (Gr. ἱστός, web; λόγος, discourse), the study of tissues and types of cells in plants and animals.

HORMONE (Gr. ὁρμάω, I stir up), a secretion which circulates in the body and influences organs and tissues other than those from which it was produced.

HYDRANTH (Gr. ὕδρα, water-serpent; ἄνθος, flower), the flower-like individuals, with nutritive function, of hydroid colonies.

INHIBIT (L. *inhibeo*, I prevent), to check. The inhibitory action of nerves reduces the activity of muscles or glands.

INSULIN (L. *insula*, an island), the internal secretion of the pancreas, produced by scattered groups of cells called the islets of Langerhans. Insulin is necessary for the utilization of sugar by the tissues. Lack of it causes diabetes.

INTESTINE (L. *intestinus*, within), that part of the alimentary canal where digested food is absorbed and the undigested residue converted into faeces.

KILOCALORIE. (See CALORIE.)

LARVA (L. *larva*, ghost, mask), a stage in the development of some animals, when, after hatching from the egg, they are self-supporting, but very different in structure and mode of life from the adult; e.g. caterpillar, tadpole.

LEUCOCYTE (Gr. λευκός, white; κύτος, vessel), a white blood-corpuscle.

LINKAGE. The tendency of certain genes to remain together from generation to generation, more frequently than would be expected on simple Mendelian principles, because they are situated in the same chromosome.

LYMPH (L. *lympha*, water), a colourless liquid, containing corpuscles, circulating in the bodies of vertebrates. LYMPHATICS, the system of vessels which contain lymph.

MAMMALIA (L. *mamma*, breast), the class of vertebrate animals which suckle their young, and possess hair.

MEDUSA (Gr. Μέδουσα; the Gorgon), a name given to the main free-swimming type of Coelenterate, the jelly-fish. (See POLYP.)

MESENTERY (Gr. μέσος, middle; ἔντερον, intestines), the double membrane, containing nerves and blood-vessels, which supports and keeps in place the gut in the body-cavity (coelom).

MESODERM (Gr. μέσος, middle; δέρμα, skin), the middle of the three germ-layers formed in the early development of most Metazoa. From it are derived, in higher forms, the muscles, the blood and circulatory system, the connective tissues, the coelom, the reproductive organs, coelomoduct excretory organs (e.g. vertebrate kidneys), and, in Vertebrates and Echinoderms, the skeleton.

METABOLISM (Gr. μεταβολή, change), a general term including all the chemical processes which take place in a living organism.

METAMORPHOSIS (Gr. μεταμόρφωσις, transformation), a relatively abrupt change in development from one phase to another with markedly different structure and mode of life. The change from LARVA (q.v.) to adult.

MITOSIS (Gr. μίτος, thread), the processes in typical nuclear division, in which the CHROMOSOMES (q.v.) appear as thread-like bodies. Also called KARYOKINESIS.

MODIFICATION. A non-heritable variation in an organism, produced by the action of the environment, or by the use or disuse of parts. (See also MUTATION, RECOMBINATION.)

MORPHOLOGY (Gr. μορφή, form; λόγος, discourse), the study of structure and form.

MOTOR (L. *motus*, motion). (See EFFERENT.)

MUTATION (L. *mutatio*, change), a sport or variety, which appears suddenly owing to a change in the hereditary constitution: a variation in an organism which appears suddenly and is inherited (see also MODIFICATION and RECOMBINATION). Most mutations affect single GENES (q.v.); others are due to the addition or subtraction of single chromosomes or sets of chromosomes.

NEUROBLAST (Gr. νεῦρον, sinew; βλαστός, germ), an embryonic cell of nervous tissue: one of the cells from which NEURONS (q.v.) are formed.

NEURON (Gr. νεῦρον, sinew), a cell-unit of the nervous system: a nerve-cell with all its processes, including the AXON (q.v.) or nerve-fibre springing from it.

NOTOCHORD (Gr. νῶτον, back; χορδή, string), a rod of cells in all vertebrate embryos, which is the precursor of the backbone, and which in some lower Chordates (e.g. Amphioxus, Lamprey) persists throughout life.

NUCLEUS (L. a kernel), a specialized part of the protoplasm in the interior of all typical cells; it is rich in chromatin, and contains the chromosomes. It is essential both for metabolism and heredity.

ORTHOGENESIS (Gr. ὀρθός, straight; γένεσις, descent), evolution in a definite direction.

OVUM (plural, OVA) (L. *ovum*, egg), a female gamete or egg.

PARASITE (Gr. παράσιτος, one who feeds at another's table) an animal or plant which lives and grows upon another living organism, and gives nothing in return.

PARASYMPATHETIC SYSTEM (Gr. παρά, beside + sympathetic, q.v.), part of the AUTONOMIC NERVOUS SYSTEM (q.v.) chiefly concerned in the stimulation of muscles and glands connected with vegetative activities like digestion, reproduction, etc., and in the inhibition of processes concerned with violent action of the organism as a whole. (See SYMPATHETIC.)

PARATHYROID (Gr. παρά, beside + thyroid, q.v.), a small ductless gland, situated near the thyroid, which controls the calcium metabolism of the body.

PERISTALSIS (Gr. περιστέλλω, I constrict), rhythmic waves of contraction and relaxation of the involuntary muscles of the gut and other tubular viscera, which force the contents along the tube.

PHAGOCYTE (Gr. φαγεῖν, to devour; κύτος, cell), amoeboid cells in the bodies of multicellular animals, which devour foreign bodies, including dead cells of the same organism, intruding bacteria, etc. PHAGOCYTOSIS, the action of phagocytes.

PHYLUM (plural, PHYLA) (Gr. φῦλον, tribe), one of the main groups of the Animal Kingdom, of which about twelve are recognized.

PHYSIOLOGY (Gr. φυσιολογία, an inquiring into nature), the study of the functions of organisms.

PITUITARY BODY (L. *pituita*, mucus), a small ductless gland at the base of the brain. It is divided into anterior and posterior lobes. The secretion of the anterior lobe appears to regulate growth; that of the posterior lobe to stimulate smooth muscle, to cause amphibian pigment cells to expand, etc.

PLACENTA (L. a flat cake), the organ in higher mammals by which the embryo is

nourished and supplied with oxygen within the mother's body. It is formed of interlocking maternal and embryonic tissue, in which embryonic blood-vessels come into close contact (but not open communication) with maternal blood-vessels. A somewhat similar arrangement is found in some sharks.

PLASMA (Gr. πλάσμα, formative material), the fluid part of blood; blood minus the corpuscles.

POLYP (Gr. πολύπους, many-footed), a name given to the sessile type of Coelenterate (e.g. Hydra, sea-anemone, coral) on account of their numerous tentacles. (See MEDUSA.)

PROPRIOCEPTOR (L. *proprius*, one's own; *capĕre*, to take), receptor organs affected by changes within the body (e.g. altered balance; differences in muscular tension).

PROTOPLASM (Gr. πρῶτος, first; πλάσμα, form), "the physical basis of life"; the living substance contained in organisms.

PROTOZOON (plural PROTOZOA) (Gr. πρῶτος, first; ζῷον, animal), a unicellular animal.

RECEPTOR (L. receiver), those organs whose function is to be sensitive to stimuli. (See EXTEROCEPTOR, PROPRIOCEPTOR.)

RECESSIVE. One form (allelomorph) of a hereditary factor whose effects are masked by another (dominant) form of the same factor. (See DOMINANT.)

RECOMBINATION. A variation in an organism produced by a fresh combination of existing hereditary factors. (See also MODIFICATION and MUTATION.)

REFLEX (L. *re*, back; *flectĕre*, to turn), a movement which takes place independently of the will, as a result of stimulation and of predetermined connexions in the nervous system: the setting into action of an effector organ, as a result of stimulation of a receptor organ, through predetermined paths in the nervous system.

SECRETIN. A secretion from the lining of the intestine which, conveyed in the blood, causes the pancreas to produce its external secretion, pancreatic juice.

SECRETION (L. *secerno*, I set apart), (1) a substance formed by the activity of a gland—e.g. bile from the liver: gastric juice from the wall of the stomach: saliva from salivary glands; (2) the formation of such a substance.

SEGMENTATION (L. *segmentum*, a cutting), dividing into parts. (1) segmentation of the egg: the division of the activated egg into a number of small cells or blastomeres; (2) metameric segmentation: the "cutting-up" of the body of many higher metazoa into a number of parts, produced originally by the reduplication of the trunk region.

SEGREGATION. The clear-cut separation of the members of a pair of hereditary factors or genes from each other before the formation of gametes; separation of a pair of genes without mutual contamination.

SENSORY (L. *sentio*, I feel.) (See AFFERENT.)

SERUM (L. whey), a watery fluid that separates from blood when it clots.

SOMA (adjective, SOMATIC) (Gr. σῶμα, body), the individual body of an organism as opposed to the germ-cells: that part of the organism limited to its individual life as opposed to that part capable of reproduction.

SPERMATOZOON (or SPERM) (plural SPERMATOZOA) (Gr. σπέρμα, sperm; ζῷον, animal), the male gamete, when markedly different from the female gamete. Most sperms are capable of active swimming.

SPHINCTER (Gr. σφίγγω, I bind tight), a circular band of muscle which can close an aperture by its contraction. E.g. the sphincter of the pylorus of the stomach.

SYMPATHETIC SYSTEM (Gr. σύν, with; πάθος, suffering), part of the AUTONOMIC NERVOUS SYSTEM (q.v.) chiefly concerned in the stimulation of muscles and glands connected with violent activities of the whole organism (e.g. defence, attack, flight, etc.) and in the inhibition of vegetative processes like digestion. (See PARASYMPATHETIC.)

THYMUS (Gr. θύμός, soul), a glandular body in the neck region, of unknown function, derived from the epithelium of certain gill-slits.

THYROID GLAND (Gr. θυρεοειδής, shield-shaped), a ductless gland situated in the front of the neck, and derived from a pocket in the floor of the pharynx. Its secretion, thyroxin, ($C_{15}H_{11}O_4NI_4$), accelerates the rate of metabolism, and causes the metamorphosis of Amphibian tadpoles.

TRACHEA (Gr. τραχύς, rough), (1) in land vertebrates, the windpipe; (2) in insects and spiders, one of a number of air-tubes which constitute the respiratory system.

TRACHEOLE (diminutive of TRACHEA), one of the ultimate fine branches of the TRACHEAE (q.v.) of insects and other land Arthropods. Tracheoles may penetrate the interior of cells.

UREA (Gr. οὖρον, urine), a nitrogenous compound ($CO_2(NH_2)_2$), the chief waste product discharged in mammalian urine. The first organic compound to be artificially synthesized.

VASOCONSTRICTOR (L. *vas*, vessel; +constrict), causing the contraction of blood-vessels.

VASODILATOR (L. *vas*, vessel; +dilate), causing the expansion of blood-vessels.

VASOMOTOR (L. *vas*, vessel; *motor*, mover), controlling the movements (contraction or expansion) of blood-vessels.

VEIN (L. *vena*), a vessel which conveys blood from the tissues to the heart. Most venous blood is dark in colour as the result of the removal of oxygen by the tissues.

VERTEBRA (plural VERTEBRAE) (L. joint), one of the cartilaginous or bony segments of the spinal column.

VERTEBRATE. An animal having a backbone. The group of vertebrates includes cyclostomes, fish, amphibia, reptiles, birds and mammals. (See CHORDATES.)

VESTIGAL (L. *vestigium*, trace), an organ which has become reduced in the course of evolution until its original function is wholly lost. E.g. the hind-limb of whales.

VITAMIN (L. *vita*, life; amine, one of the compound ammonias), "an unknown but essential accessory factor of diet." Several different vitamins exist. Their absence leads to such diseases as beri-beri, scurvy, etc.

ZYGOTE (Gr. ζυγωτός, joined together), the cell produced by the fusion of the gametes in sexual reproduction. In Metazoa this is the fertilized ovum.

BOOK III

THE MIND AND ITS WORKINGS

BY C. E. M. JOAD

CHAPTER ONE

INTRODUCTORY: THE MIND-BODY PROBLEM

SPECULATIVE CHARACTER OF PSYCHOLOGY

PSYCHOLOGY IS THE science of the mind; it seeks, in other words, to give an account of the way in which the mind works. Unlike other sciences, however, it is concerned less with facts than with theories. Chemistry, for example, presents us with a number or facts about the elements of matter, and arranges these facts in accordance with certain laws; nobody doubts that these facts are facts, or denies that the laws which the facts are said to exemplify really do apply to them. So certain are scientists about these laws that they are enabled by means of them confidently to predict the occurrence or facts which do not yet exist. They can tell you, for example, that it you combine two parts of hydrogen with one of oxygen the result will quite certainly be water. And what is true of chemistry is true of all the sciences in a greater or less degree. But it is not true or psychology for the reason that in psychology there are no facts which everybody agrees to be facts, and, as a consequence, there are no universally accepted laws in terms of which the facts can be explained. In other words, although you can say that a stone will fall downwards if you drop it from a window, you cannot be sure that man will lose his temper if he sits on a pin; you cannot even predict that he will swear.

To put the point in another way, psychology still belongs very largely to the province of speculation. We cannot say that the mind works in this way or in that way; we can only wonder and propound theories about it; and on the great majority of important questions there are several contradictory theories. This does not necessarily mean that psychology will never attain to certain and agreed knowledge. All the sciences were born into the realm of speculation; they all, in other words, started life as philosophy. The ancient Greeks *wondered* about the stars, about the properties of matter and about the functions of the human body; for them all these branches of inquiry

formed part of philosophy. So soon, however, as anything definite came to be known about these matters, they ceased to be philosophy and, under the names astronomy, physics and physiology, became sciences in their own right.

Now psychology is in a transition stage. In some very few respects it has attained definite knowledge and is entitled, therefore, to be called a science; but with regard to the great majority of the questions it studies it has still to emerge from the phase of wondering or speculation. What is more, and here we come to a very disturbing fact, whenever psychology does manage to obtain a piece of definite, accurate and agreed knowledge, it turns out to be knowledge not about the mind but about the body. Why is this?

The discussion which an answer to this question involves, besides being interesting in itself, will admirably serve the purpose of introducing our subject, and I propose, therefore, to occupy the remaining pages of this introduction by indicating as briefly as I can what the answer is.

THE RELATIONSHIP OF MIND AND BODY

It is obvious that one of the most important things about the mind is its relationship to the body. Mind and body are continually interacting in an infinite number of different ways. Mind influences body and body mind at every moment of our waking life. If I am drunk I see two lamp-posts instead of one; if I fail to digest my supper, I have a nightmare and see blue devils; if I smoke opium or inhale nitrous oxide gas I shall see rosy coloured visions and pass into a state of beatitude. These are instances of the influence of the body upon the mind. If I see a ghost my hair will stand on end; if I am moved to anger my face will become red; if I receive a sudden shock I shall go pale. These are instances of the influence of the mind upon the body. The examples just quoted are only extreme and rather obvious cases of what is going on all the time. Many thinkers indeed assert that mind and body are so intimately associated that there can be no event in the one which does not produce some corresponding event in the other, although the corresponding event, which we may call the effect of the first event, may be too small to be noticed. The interaction between mind and body is, at any rate, a fact beyond dispute.

Yet when we come to reflect upon the manner of this interaction, it is exceedingly difficult to see how it can occur. Mind,* it is clear, must be something which is immaterial; if it were material it would be part of the body. The contents of, or the events which happen in the mind—that is to say, wishes, desires, thoughts, aspirations, hopes, and acts of will—are also immaterial. The body, on the other hand, is matter, and possesses the usual qualities of matter, such as shape, size, weight, density, inertia, occupancy of space, and so forth.

Now there is no difficulty in understanding how one material thing can be influenced by another. Each possesses the same attributes of size, shape and weight, in virtue of which each can, as it were, communicate with or "get at" the other. Thus a paving stone can crush an egg because the egg belongs to the same order of being as the stone. But how can the paving stone crush a wish, or be affected by a thought? Material force and mass have no power over ideas; ideas do not exert force nor do they yield to mass. How in short can that which has neither size, weight nor shape, which cannot be seen, heard or touched, and which does not occupy space, come into contact with that which has these properties?

Mind and matter seem, then, to belong to two different worlds, to partake of two different orders of being, and the problem of their interaction is the problem of the whale and the elephant raised to the *n*th degree. In these circumstances the question immediately arises, "Is it really necessary when accounting for the operations of the human body to postulate the intervention of mind after all?"

THE WORKING OF THE NERVOUS-SYSTEM

Let us look at the question in a little more detail. Suppose that I place my hand upon the poker, find that it burns me and quickly withdraw my hand. What exactly is it that has happened? The heat of the poker stimulates the terminals of the nerve cells in my fingers. These nerve cells or neurones are in contact with other nerve cells, and a stimulus applied to any one of them is accordingly passed on to the next. The machinery of transference is as follows: Each nerve cell has a number of filaments attached to and extending from it.

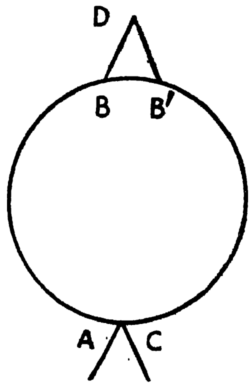
*It is important to emphasize the fact that the word "mind" does not mean the same as the word "brain"; the brain *is* material.

These filaments are known as dendrites. One filament is considerably longer and finer than the others, and is known as the axon, and it is through the axon that the stimulus or impulse passes through to the next neurone or nerve cell in the chain. The points of contact between the axons, known as synapses, act like valves; that is to say, they let the stimulus or impulse pass in one direction only; it is not allowed to return on its track. The central part of the nervous-system, forming a sort of highway along which all impulses pass, is the spinal cord. Travelling by this road the heat stimulus to the nerve cells in my fingers reaches the brain. Here it enters a complicated system of tiers and layers of neurones. These tiers or layers act as the clearing houses of the nervous-system, sorting out the different messages received from all parts of the body, and determining which of them shall be passed on for the purposes of action. Passing on a stimulus for the purposes of action means transferring it to another system of neurones, known as the effector nerves or motor nervous-system, which govern the movements we make, as opposed to the receptor nerves or sensory nervous-system, which receive and transmit the sensations we feel. Assuming that the brain has decided to take action in respect of the stimulus from the poker, it lets the stimulus pass through to the neurones composing the motor nervous-system; these in their turn pass on the stimulus received from the brain to the fingers, as the result of which the latter are withdrawn from the poker. The whole procedure may be likened to sending a message from the fingers to the brain in response to which another message is sent back to the fingers. Now the processes involved in the sending of these messages, complicated as they appear, seem, nevertheless, when we look at them from the point of view of the body, to be purely automatic. It is like putting a penny into a slot machine and taking out a box of matches. Nor does it appear to be necessary to introduce a mind or consciousness at any stage of the process to explain what it is that happens or why it happens. It may be true that we *feel* the heat of the poker, and that the feeling is a psychological or mental, as opposed to a physiological or bodily event; but it may also be true that the feeling has nothing to do with the withdrawal of the fingers, which is a purely automatic result of the applied stimulus.

I have deliberately taken the simplest possible case, and one in which

the action of the body is, on any view of the mind-body relationship, as nearly automatic as it is possible for it to be. But if we can explain some of our actions, however simple they may be, without introducing this mysterious thing mind, may it not be possible that *the same sort of explanation*, enormously complicated, of course, but still confining itself purely to bodily terms, might be invoked to account for all our actions? In any event should we not in the interests of science leave no stone unturned in order to make it do so, hoping that an increase in knowledge about the body will cause the gradual disappearance of many difficulties which at present beset the attempt to explain, not only action but thought in bodily terms?

Since this is the fundamental problem of all psychology upon which modern psychological controversy very largely turns, let me try to put the point in a somewhat different way.



Let us suppose that in the diagram ABB′C is a circle which roughly represents the passage of a stimulus or impulse round the nervous-system. The stimulus is applied to A (the fingers), and passes into the brain at B. I have marked off a definite segment of the circle from B to B′ to indicate the fact that there is a definite passage through the brain, the point at which the impulse leaves the brain at B′ being different from that at which it enters at B. This is a passage through exceedingly complicated tiers of neurones which apply a process of sifting or sorting to the impulses received, with a view to determining which of them shall be passed on to the motor apparatus for action. The part of the circle from B′ to C represents the motor or effector apparatus, C being again the fingers, or in other words the point at which the motor impulse travelling down to C causes us, as we say, to take action.

Now the point at issue among modern psychologists is this: is the passage of an impulse round the nervous-system a passage which can be completely described at every stage in physiological terms, sufficient in itself to explain what happens whenever the organism feels and acts? If it is, then we may think of bodily actions on the analogy of

the movements of water in a full reservoir. One pipe leads into the reservoir, another out of it; whenever, therefore, fresh water comes in through the first pipe, it will cause an overflow of water which will be drained off through the second. The process is a purely automatic one and takes place in accordance with physical laws. Whenever, in other words, a stimulus is applied at one end of the chain, then the appropriate reaction will occur at the other.

If it is not, then we must assume that this nervous chain is broken; that when the impulse reaches the first B, it leaves the brain altogether and passes out of the circle into something of an entirely different nature from B, which we will call D, the mind. How this occurs we do not know; but, if it does occur, the result will be, first, that we shall, as we say, be aware of or feel the stimulus; secondly, that this awareness or feeling will be a purely mental event not explicable in bodily terms; and thirdly, that having experienced it, the mind may or may not decide to give effect to the stimulus by instructing the brain to set the nervous-system to work to remove the fingers. The nervous-system will in the former event begin to work again—indeed, it must operate if action is to follow—but it will come into operation after a break, during which the body has ceased to function and something which is not the body has taken charge.

THE ALTERNATIVE EXPLANATION

This, putting the point very crudely, is the other alternative, and it involves a hypothesis, the hypothesis of the existence of a mind, of something, that is to say, which is not of the same order of being as the body, which all those who are dissatisfied with the materialist view must in some form or other adopt. In favour of it there is the obvious fact that we do not seem to be the mere slaves of our bodily stimuli, slot machines which, when the penny is inserted, work because we must, but appear to be endowed with a power of choice, in virtue of which we can decide whether or no we shall obey them, and if we do, in what way. If, for example, I am hanging on to the edge of a precipice with one arm and a wasp stings my hand, I shall probably not withdraw the hand, in spite of the stimulus which it has received. Facts of this sort are difficult to explain without introducing mind. An explanation can indeed be given in physiological terms, but

it is exceedingly complicated and has the appearance of merely pushing the problem further back.

We can say, for example, that another set of impulses stimulating the fingers to retain a tight hold of the precipice edge is already in command of the effector nerves leading to the arms, that these nerves cannot, therefore, be utilized by the withdrawing impulses unless the holding-on impulses are first ousted; that two sets of impulses are, therefore, in competition for the use of the effector nerves, and that the nervous centres in the clearing house of the brain determine which of the two sets shall employ the effector nerves, by getting control of what is known as the "final common path." But is this determining process a purely automatic one, depending on the relative strength of the two sets of impulses; or does it not in itself presuppose a mental act of decision which instructs the clearing house in the brain which set of impulses to let through and which to keep out?

The mental hypothesis is beset with the general difficulty to which I have already referred—the difficulty, namely, of conceiving how what is non-material can act on matter.

The next two chapters will be concerned with the elaboration of these two alternatives. In Chapter Two I shall consider various forms of the materialist psychology—that is to say, of that kind of psychology which, since it endeavours to explain everything that happens without introducing a mind, is not really psychology at all but physiology. In the third chapter I shall consider the objections to this mode of interpretation, objections which, if they are valid, lead to the view that we cannot explain the facts of psychology without bringing in the mind.

WHY PSYCHOLOGY IS CONTROVERSIAL

Besides serving the purpose of providing a general survey of the ground to be covered, the above discussion enables us to answer the question which we raised at the beginning of the chapter—the question, namely, why it is that psychology still belongs in the main to the realm of speculation and hypothesis rather than to that of exact scientific knowledge.

That this must necessarily be the case, so long as the fundamental question of psychology—the question whether there is a mind to

study—remains controversial, is obvious. But there is a further special reason for the inexact character of psychological knowledge.

Returning for a moment to the diagram given above let us presuppose the truth of the mental hypothesis, and assume, accordingly, that the stimulus on reaching B leaves the circle of the nervous-system and causes or becomes a set of occurrences of an entirely different order, occurrences which we call feelings of pain, shock, or warmth, which happen in the mind (D). It will still be the case that with regard to these mental occurrences, feelings, emotions, and sensations, we shall be able to affirm practically nothing which is at once exact, definite, and generally agreed. The nature of the emotions and feelings, for example, is, as will be seen in a later chapter, one of the most controversial subjects in psychology. What is true of the emotions or feelings is equally true of all mental events. It turns out, in fact, that when we do obtain exact and reasonably certain knowledge of the workings of that compound whole which is partly mind and partly body, it is knowledge about the bodily side of it.

About the parts of the circle which lie between A and B, and B′ and C, we are actively increasing our stock of detailed scientific knowledge. We can manipulate the nervous-system in various ways in the confident expectation that such and such results will follow. But the part of the process represented by the lines BD and DBB′ is still shrouded in obscurity, and it is doubtful whether we shall ever be able to give an exact account of it. Certainly we cannot do so yet, a fact which many regard as constituting a strong argument for cutting out D altogether.

This is what is meant by saying that psychology, so far as it deals with facts, so far, that is to say, as it is scientific, is not psychology at all but physiology.

CHAPTER TWO

THE MIND AS AN ASPECT OF THE BODY

I PROPOSE IN THIS chapter briefly to outline those theories of psychology which seek to interpret the facts of human consciousness and behaviour without postulating the existence of a distinct and unique entity called mind. By the word mind I mean something which is not material, which is not, therefore part of the body, and which does not obey the laws of chemistry and physics which the body obeys; in this sense all the theories with which we shall be concerned may be called materialist. Some of these theories do indeed admit the *possibility* of the existence of mind in the sense described, but they nevertheless affirm that, if it does exist, its only function is to be aware of events that occur in the body. It does not initiate these events nor does it control them; it merely registers them, what we call a thought or a feeling being a mental reflection of a disturbance in the brain or the body.

Theories of this latter type may also be classed as materialist, since, in denying to the mind any directive or creative function, they do in fact assert that the important thing about the individual is his body, implying thereby that his thoughts and behaviour will ultimately be found to be explicable in terms of the laws which govern material bodies—that is to say, the laws of physics and chemistry.

We are concerned, then, with the view of human psychology which says: "Either there is no such thing as mind, or, if there is, then everything which happens in the mind is a mere reflection of something that has first happened in the body." This view was very widely held in the nineteenth century, and is advocated by many psychologists in a somewhat different form today. We will consider first its nineteenth-century form.

NINETEENTH-CENTURY VIEW OF MIND

It must be remembered that the tendency of nineteenth-century science was to belittle in every direction the importance of the part played by mind in the scheme of the universe. The work of Darwin

had been used as the basis of a conception of evolution, in which the advance of life from the primitive amœba to the fully developed man was described and accounted for without postulating the intervention of mind at any stage of the process. It was to variations in species, to the fact that offspring did not entirely reproduce the characteristics of their parents, that the development of life was due, and, when pressed for an explanation of the question how and why these variations occurred, Darwin confessed to a complete agnosticism. They just happened, fortuitously it must be presumed, and those which were suited to their environment survived. The only other theory in the field, that of the French materialist Lamarck, ascribed the origin of variations to the influence of environment. The environment changed, and the species either adapted itself by changing with it, or paid the penalty for its inability to do so by extinction. In any event the process was automatic; the movement and development of life was due not to the fulfilment of a purpose, or the execution of a plan, but to the influence of external material conditions upon living organisms. For the root cause of vital occurrences we must, in short, look to changes in material conditions.

Geology and astronomy reinforced these conclusions. Geology had enormously extended the age of the world, astronomy the size and spread of space, and in the vast immensities of geologic time and astronomic space life seemed like a tiny glow flickering uncertainly, and ultimately doomed (when, for example, the sun grew too cold to maintain suitable conditions upon the earth) to go out altogether. Life, then, was a chance occurrence in a fundamentally mindless universe, a passenger across an alien and indifferent environment, destined to finish its pointless journey with as little noise and significance as, in the person of the amœba, it began it. Meanwhile it would continue to be at the mercy of material forces; changes in life would reflect and be conditioned by prior changes in matter, and living organisms, instead of being the cause of physical events, would merely register their occurrence.

It will be seen, therefore, that the tendency to reduce the status and importance of mind, to subordinate it to material forces, and to think of causation as proceeding always from the more material to the less, was already in the air, and contemporary psychology merely carried

it to its logical conclusion. Among the infinite permutations and combinations through which the forms of matter had passed in the course of its evolution, there had occurred one in which, so psychologists argued, matter had become conscious of itself. It was this self-consciousness of matter that was called mind. Mind, then, was a highly refined and attenuated form of matter, a sort of halo surrounding the brain. Its function was to light up the events occurring in the brain, and when this illumination occurred we were said to be *conscious* of the events.

MIND AS A REFLECTION OF THE BRAIN

The function of the mind being limited to lighting up or registering events occurring in the brain, it is clear that it cannot register what is not there; it follows that there can be no event in the mind unless there has been a preceding event in the brain. Mental events are, therefore, never the cause but always the effect of bodily events. We are all familiar with the kind of interpretation which explains mental occurrences with remarks such as, "I have been walking in an east wind which has given me a headache and made me depressed"; or, "I have been drinking heavily all my life and am beginning to see things"—explanations which account for what occurs in the mind in terms of what has first occurred in the body; and it is precisely this type of explanation which was now extended to cover willings, wishings, thinkings, hopings, and rememberings, in a word all the workings of the mind. Hence just as in the universe outside, so also within the individual organism causation proceeds always from the more material to the less.

Man is the creature of external forces, and his mind is the creature of his body; just as changes in man's body are due to changes in the environment to which he reacts, so also are changes in his mind due to his bodily reactions to his environment. Thus the chain of physical causation, from the stirrings of life in the first speck of protoplasmic jelly to my thoughts as I am writing this book, may be regarded as complete. Many links have still to be established; it is, for example, at present only possible in a very few cases to say how and in what way the body determines the workings of the mind, but the filling in of detail is simply a question of further research; the main outlines of the

picture are already sufficiently clear enough to be comprehended.

It is obviously impossible within the limit of a short chapter to indicate all the ways in which physiological psychology seeks to fill in the details, in its attempt to explain mind action in terms of bodily action. I propose, however, to give a few instances of explanations of mental happenings that have in fact been advanced, in order that the reader may form for himself an opinion on the practicability of the attempt. I will choose as examples physiological accounts of the emotions and the will, and then devote a few pages to a brief description of the so-called Behaviourist psychology, which dispenses with the conception of consciousness altogether.

THE EMOTIONS

A celebrated theory of the emotions which admirably illustrates the materialist attitude to psychology is that propounded by the psychologist William James in collaboration with Professor Lange. The general standpoint of William James was not by any means identical with that of the materialists, but it so happens that his theory of the emotions fits very well into the materialist framework.

To the plain common-sense man his emotions appear to be aspects of his psychological being, which are called into action by the perception of an external situation which, as we say, arouses them. If we see a ghost, we feel frightened; if we see a child torturing a kitten, we feel indignant. The emotion is in each case thought to be, as it were, permanently there, even when it is latent, a sort of continuing factor in our psychology, waiting for the appropriate situation to call it into action. It was this kind of conception, which we may call the ordinary view of the emotions, that the James-Lange theory denied. Its authors were sceptical of the existence of these emotions as separate psychological entities, did they, for instance, exist when they were not active, and if so, where?

Their view very briefly was that an emotion was the perception of a physiological change in ourselves. For example, it is found that when we feel the emotion of fear, some glands situated on the kidneys known as the adrenal glands, discharge a certain amount of fluid secretion, which in its turn produces important changes in the tensions of the muscles and in the blood, resulting in increased rapidity of

heart-beat and dilatation of the pupils. The awareness of these bodily occurrences constituted, according to William James, the emotion of fear. Now the question at issue between the exponents of the James-Lange theory and those who adopt what I have called the common-sense view is simply this: Does the fear emotion precede and cause the gland excretion, or does the gland excretion precede and cause the fear emotion?

Many experiments have been made with a view to testing the conclusions of the James-Lange theory, but unfortunately no way has been found of settling the question at issue in a manner which is satisfactory to both parties. All that the facts entitle us to say is that the bodily event and the mental event are found in invariable accompaniment. Our view as to which precedes and causes which will depend upon our general attitude to the mind-body problem. When James said that an emotion was simply a mental awareness of a preceding physiological event, he was invoking that conception of the mind which regards mental activity as being always a reflection or register of preceding bodily activity, to which we have referred. As he puts it, "We feel sorry, because we cry." If there occurred neither tears nor any of the other physiological accompaniments of sorrow, we should not feel sorry.

INSTINCT IN ANIMALS

Modern materialists are inclined, it is true, to doubt whether the mere occurrence of a bodily disturbance is in itself sufficient to cause the emotion. They are inclined to say that the *first* thing that happens to us when we see a tiger is an instinctive adaptation to the situation, which takes the form of physical flight. This instinctive adaptation results in modifications of the heart-beat, of the breathing, and so forth, which are designed to facilitate flight, and it is our awareness of these modifications which is the emotion of fear. In other words, the beginning of the whole chain of events which ends in the emotion is an instinctive tendency to act in a special kind of way. The question of whether this instinctive tendency is itself explicable on materialist lines raises the further question of the nature of instinct in general with which we shall deal in a later chapter. For the present it will be sufficient to point out that, even if we assume an instinct to be the first chain

in the sequence of events which ends in emotion, there is no insuperable obstacle in the way of a physiological account of the origin of instinct. So much, at least, emerges from a consideration of animal psychology.

ANIMAL PSYCHOLOGY

We may perhaps take this opportunity of mentioning the fact that it is to animals rather than to human beings that psychologists have increasingly directed their attention in recent years. The processes of an animal's mind are simple and their connexion with bodily stimuli is easier to detect; moreover nobody wishes to think that animals are either virtuous, reasonable, or æsthetic, and there is accordingly less danger when dealing with animal psychology that the acceptance of theories, which have nothing to recommend them but their truth, will be prejudiced by the consideration that they presuppose a gloomy, a low, or a pessimistic view of animal nature. Researches into the nature of instinct in animals have shown that many instincts of first-rate importance are dependent upon, if they are not entirely conditioned by, physical stimuli. For example, the French psychologist Giart has shown that the instinct of maternal affection in the hen, instead of arising spontaneously at certain periods in the hen's life cycle, as, for example, when she is about to sit, is dependent upon, if it is not identical with, the occurrence of local inflammation. It is the local inflammation which causes the hen to sit upon the eggs in order to allay it, and if suitably irritated with pepper in the appropriate places the most unbroody hen will develop into an excellent foster mother. Even if, therefore, there is a psychological entity in the hen of the kind known as the maternal instinct, it is merely a reflection of a preceding bodily disturbance, just as an emotion, if it is a mental event at all, reflects and depends upon a number of such bodily disturbances.

THE WILL

The will appears to constitute one of the greatest obstacles to a materialist interpretation of psychology. It seems to be the most spiritual kind of faculty we possess—that in virtue of which we are not only distinct from matter, but even in some respects able to

dominate it. When, for example, we decide to perform so simple an action as lifting our right arm over our head, we seem to be not so much the servants of matter acting in response to physical stimuli, but rather to command and dominate it, and to command it in virtue of our being in some sense free. To be free means to be exempt from the law of cause and effect, to be able, in other words, to exert our wills spontaneously and on our own initiative, without there being anything to cause us to do so. How can this feeling that we undoubtedly have of freedom from material causation be explained on materialist lines?

Although we cannot prove that in *all* cases in which we appear to will and to will freely we are simply reacting to bodily stimuli, we are nevertheless able to show that by applying appropriate stimuli we can cause people to have experiences which are exactly similar to the experience of willing freely.

I mentioned in the first chapter the fact that the parts of the nervous-system which govern the movements of our limbs, are dominated by certain tiers of nerves in the brain which act as clearing houses, and determine which of our impulses shall be passed on to the motor nervous-system for the purposes of action. These clearing houses are called association centres, and they discharge the impulses which are being "let through" into what are called the excito-motor centres, which form part of the cortex or outside surface of the brain. These lie in a band roughly from ear to ear over the top of the head. Now if these centres are stimulated with a mild electric shock, they transmit impulses along the motor neurones and the patient moves his limbs. This, it might be said, does not prove anything. It is common knowledge that if the appropriate stimulus is applied to certain parts of the body, an automatic movement of the limbs will result; if, for example, the legs are crossed and the upper leg is gently struck below the knee-cap with the side of the hand, the foot will jerk upwards; if you are unfortunate enough to get a fly into your eye, you will immediately close your eyelid. Actions of this type are called reflex actions; they are purely automatic, and they have nothing to do with the exercise of the will. This is true, but the surprising fact about the electrical stimulation of the excito-motor centres is that it causes in the patient not only a movement of the limbs but the feeling that he

is moving his limbs voluntarily; it seems to him, in short, that he has willed to move them. If, then, it is possible to cause a mental experience inseparable from what is called willing by the application of a physical stimulus to the brain, may it not be true that acts which are called free will *always* be found to have some physiological cause, in which event they cannot really be free?

CONSCIOUSNESS AND THE SELF

It might well seem that consciousness is the most indubitably mental thing about us, the very source and centre of our mental life, and that it would prove, therefore, most intractable to the physiological method of treatment of which we have been giving instances in this chapter. Many thinkers have, indeed, so regarded it, basing upon the fact that the one thing in the universe of which we are most certainly aware is our experience, an experience which is both mental and conscious, what are called Idealist theories of reality. It is nevertheless possible to approach consciousness, in common with all other mental phenomena, from the physiological standpoint. This method of approach yields somewhat startling results, many physiologists, from William James onwards, having been led to doubt the very existence of consciousness as an independent, separate item of our mental make-up. I will try very briefly to indicate the reasons for this sceptical attitude to consciousness.

In the first place consciousness is something which is supposed to be possessed by or to belong to the self. Yet this self in which consciousness resides is a something of which we have no knowledge, and whose very existence is a hypothesis. Try as we may to discover the self, we never succeed in tracking it down; what we do come upon when we endeavour to realize the self, is, as the philosopher Hume pointed out, a something which is willing, a something which is desiring, a something which is thinking, or, in the particular case in question, a something which is wondering whether there is such a thing as a unified self and trying to discover it. Now there is nothing to show that all these "somethings" are the same thing; there is nothing to show even that they belong to the same thing, or that there is a unity behind them all, binding them together, yet in some sense other than they. We meet, in other words, with willings, desirings, and

thinkings, but never with the self which wills, desires, and thinks. Now it is precisely the same difficulty which confronts us when we try to track down consciousness, for the reason that consciousness is the chief characteristic of this hypothetical self. We meet with thoughts, feelings, and desires to which the quality of being conscious attaches; but we never discover a unity which is an entity called consciousness, which is other than and in a sense the source of the conscious thoughts, feelings, and desires, such that, even if, at a given moment, there were no conscious thoughts, feelings, or desires actually occurring, we could nevertheless affirm that consciousness as a separate thing or entity would still persist. But although we do not find consciousness except in so far as we experience thoughts, feelings, and desires, to which the quality of being conscious attaches, we do find thoughts, feelings, and desires without any such quality attached to them, a fact which seems to suggest that consciousness is not after all an important, permanently continuing thing, without which our mental life could not go on, but an incidental casual sort of phenomenon which may or may not attach to our mental acts without making any perceptible difference to them.

Thus in ordinary daily life it is a common experience to discover that we have been perceiving all manner of things of which we have not at the time been conscious. If, for example, I suddenly begin to attend to what lies within my field of vision, concentrating particularly upon what lies at the edge of the field, I find that I am seeing far more than I am ordinarily aware of seeing, dust on a book, a splash of ink on the desk, and so forth. Yet since my field of vision has not changed, I must infer that in some sense I have been seeing these things all the time, before, that is to say, I became conscious of them. It is clear, then, that it is by no means necessary for a mental experience, as constituted for example by an act of seeing, to be conscious in order that it may take place.

Now it has always been realized that many of our actions are performed unconsciously, as, for example, the circulation of the blood, the growing of hair and nails, the balancing of the body, or the making of a habitual gesture; but it has also usually been held that these actions are sharply distinguished from those which are normally regarded as conscious. Thus the activities of a human being are often

divided into those of which he is conscious and those of which he is not. Now one of the most interesting things about a good deal of modern psychology is that it proceeds as if this difference did not exist. It endeavours, in other words, to interpret and describe all the things we do and think without introducing the concept of consciousness at all. Those who approach psychology in this way are called Behaviourists.

THE BEHAVIOURIST PSYCHOLOGY

(i) *Our Knowledge of Ourselves.*—In order to see how they arrive at this position, it is necessary to consider what are the ways in which we know what is going on in a person's mind. They are two: introspection and observation. Of these two methods introspection is denounced by the Behaviourist as being faulty and misleading. Introspection can be applied to ourselves; yet it is extraordinary how inaccurate and unsatisfactory are people's accounts of their own experiences. Ask a dozen men confronted with a "certain situation" to describe to you what it is that they are seeing, and each of them will give you a different account.* What is more, so far from a man's capacity for introspection being improved by training the more trouble he takes to find out exactly what his conscious processes are, the less likely is he to succeed. The reason for this apparent paradox is simple enough; it is that the trained observer knows what to expect. For example, the naturalist, taking a walk, will see more than the ordinary country walker, because he knows what to look for and where to look for it, while scientists, as is well known, progress by the method of intelligent expectation, which is merely another name for inspired guessing. But the capacity for intelligent expectation,

*At a Psychology Congress held at Göttingen a clown suddenly burst into the Congress hall closely pursued by a negro. The negro caught him, leapt upon him, and bore him to the floor, where a fight ensued, which was ended by a pistol shot, after which the clown got up and rushed out of the room, still closely pursued by the negro. The whole scene, which had been carefully rehearsed and photographed in advance, took less than twenty seconds. The President then informed the Congress that judicial proceedings might have to be taken, and asked each member to write a report, stating exactly what had occurred.

Forty reports were sent in. Of these, one only contained less than twenty per cent of mistakes in regard to the principal facts; fourteen contained from twenty per cent to forty per cent mistakes; thirteen contained more than fifty per cent mistakes. In twenty-four, ten per cent of the details recorded were pure inventions. In short, ten of the accounts were quite false, ranking as myths or legends, twenty-four were half legendary, and six only were even approximately exact.—From *Public Opinion*, by Walter Lippmann.

while constituting a valuable asset to the physicist or the physiologist who is studying a subject-matter which is not affected by the expectations he forms of it, is a drawback to the introspective psychologist. When it is your own mind which you are investigating, the objects at which you are looking form part of and belong to the very instrument with which you are looking at them; it is to the mind that you are looking, and it is with the mind that you look. The result is that it is exceedingly difficult to avoid seeing what you expect to see. And the more psychology you know, the more certainly will you find what you expect to find, with the result that introspection has been chiefly used to provide psychologists with data for the theories of mind in the interests of which they resorted to introspection. Results of this kind are of course completely unscientific, and have led many thinkers completely to deny the value of introspection as a method of obtaining information about the mind.

(ii) *The Observation of Behaviour.*—The denial of the validity of introspection as a psychological method is the starting-point of the Behaviourists. Observation, and observation alone, is, in their view, the method which a scientific psychology will consent to pursue, and much of the uncertainty of psychology in the past is said to have been due to the neglect of a proper scientific approach to the subject.

Now we cannot observe mind or consciousness; we can only observe actions. Actions, therefore, in the widest sense of the word, from the raising of a limb to the secretion of fluid by a gland, are regarded as the proper subject-matter of psychology, and are studied as such by the Behaviourists. As for mind and consciousness, we do not at this stage positively say that there are no such things; but, if there are, it is quite clear that we can know nothing about them; we will confine ourselves, therefore, to actions or behaviour and see how far our interpretation of psychology in terms of behaviour will carry us.

Starting from this standpoint the Behaviourist proceeds to a study of the observable responses which different situations excite in living organisms, and correlates his observations until he can present us with a fairly exact and extensive picture of the interconnexions between these situations and the responses they call forth. It is surprising how much of our psychology, including even the workings of the alleged

mind itself, is found to be explicable on the stimulus-response basis. I cannot attempt within the limits of this chapter to give even the briefest account of the enormous amount of experimental work that has been carried out in this direction. It will be desirable, however, to describe in some little detail one set of experiments and the conclusions that have been based upon them, in order that the reader may understand the way in which the Behaviourist goes to work. The experiments in question are those associated with what is called the conditioned response.

(iii) *The Conditioned Response.*—A dog is tied up in a dark cabinet in which he is screened, so far as possible, from all outside or distracting influences. Food is put before him and his mouth begins to water; the stimulus of the food causes, in other words, a response which takes the form of excretion by the salivary glands. This is called an unconditioned response to an unconditioned stimulus. The next time that food is put before the dog, a particular note is sounded; and this is done on each of a number of succeeding occasions, the food always being accompanied by the sounding of the note. After a time the note is sounded alone, whereupon it is found to cause the salivation which in the first instance was excited by the food. In other words, the salivation response is now produced by a new stimulus, which has come to be associated with the original stimulus through constantly accompanying it. Salivation in response to the note is called a conditioned response to a conditioned stimulus. Practically any stimulus which is applied sufficiently often in conjunction with the food stimulus can be conditioned in this fashion. This is true even of a painful stimulus. Let us suppose that the dog is severely pricked when the food is put before him, and is later pricked in the same place without the food; instead of causing symptoms of pain and fright, the prick will now merely produce abundant salivation.

Two points about this interesting series of experiments may be noticed. In the first place the conditioning of the note alone as a stimulus to salivation only takes place if the note has been sounded immediately prior to or at the same time as the presentation of the food; if the note is struck after the food has been presented, it does not become conditioned. Secondly, the effectiveness of the stimulus of the note when sounded alone in producing salivation only lasts for a

certain period; if the note is sounded without the accompaniment of the food too frequently, it ceases after a time to produce salivation.

The physiological explanation of these occurrences is difficult, nor is it strictly relevant to our present purpose. Briefly it is held that the constant arrival of the food impulse and the note impulse together tune up two sets of neurones in the particular centre which receives them, so that both the neurones which are stimulated by the food impulse and those stimulated by the note are, to use a metaphor, keyed at the same pitch. Each set of neurones remains tuned up to this pitch for some time after the stimulus has ceased, with the result that either set is able, when stimulated, to discharge its impulses along the paths of the other. They can, in other words, exchange the impulses they receive and the motor actions which the impulses prompt. Next time, therefore, that either of the stimuli recurs, it finds both sets of neurones tuned to receive it, and in stimulating the one set is enabled at the same time to send a train of impulses down the other—that is to say, in the case in question, the note impulse sends a message down the neurones which determine the activity of salivation.

Now what can be done with dogs can be done also with human beings; but owing to the greater complexity of the human nervous system and the difficulty of segregating the human being from all other distracting stimuli, it is much harder to establish the connexion between stimuli upon which conditioning depends. Experiments are most successful with small children. For example, Professor Watson, the founder of Behaviourism, reached some interesting conclusions with regard to the conditioning of the responses which we associate with fear. He discovered that there are only two kinds of unconditioned stimuli which cause fear in the baby, loud noises and the feeling of being suddenly left without support. Nevertheless a normal three-year-old shows fear for a number of things—e.g., darkness, mechanical toys, animals, and so on. All these objects are, in Professor Watson's view, instances of conditioned stimuli; they cause fear because at some time or another the appearance of, for example, a dog has coincided with the occurrence of a loud noise, or with the infant being knocked over—that is to say, with a feeling of lack of support.

(iv) *The Conditioning of Emotions.*—This hypothesis, if correct, throws an interesting light on the origin and nature of emotion.

According to Watson, the number of unconditioned emotional reactions is three only—fear, the causation of which we have just described; rage, which is occasioned by the hampering of bodily movements; and love, which is elicited by stroking the skin, tickling, gently rocking, or patting. It follows that any particular object may become a conditioned stimulus for fear, rage, or love, according as it has at some time or another habitually accompanied as a stimulus the unconditioned stimuli of one or other of the emotions in question. This is a fact which, if it can be substantiated, carries with it implications of immense practical import, besides throwing a considerable amount of light upon the nature of our mental processes. By appropriately manipulating our stimuli we shall be able to introduce Christianity by transforming our enemies into stimuli for love rather than for fear, and to feel affection rather than anger for the railway official whose dilatoriness causes us to miss a train. In a word, the whole texture of our emotional life could be changed by associating the stimuli, which now causes unpleasant emotions, with those unconditioned stimuli which call forth responses which are pleasurable.

It seems probable, however, that successful results could only be hoped for in very young children, since adults would not submit to the long and laborious process which the reconditioning of their responses would involve.

(v) *Dispensing with Consciousness*.—A word may now be added on the question with which we began this section, the question, namely, of the existence of mind or consciousness. It must be admitted that the Behaviourists have met with a surprising amount of success in their endeavour to interpret psychology without postulating the intervention of mind or consciousness. In this connexion it should be borne in mind that the phenomena that we have been describing are mechanical in character, the responses following the stimuli with as much certainty as the tanning of the skin follows its exposure to the stimulus of sunlight. It is not necessary for mind to be aware of the responses in order that they may occur, nor, it may be surmised, could mind prevent these occurrences by becoming aware of them.

Is it necessary, therefore, to postulate the existence of consciousness at all? Taking our standpoint from the observation of behaviour, which is the only point of view that the Behaviourists accept as legiti-

mate, what is the difference between an action of which, as we say, we are conscious and one of which we are unconscious? The only observable difference is that the activities of the neurones and glands —that is to say, the happenings in the nervous-system which accompany the actions are different in the two cases. These different bodily activities include, in the case where consciousness is said to be present, our vocal movements when we speak of what we are experiencing.

Since this difference of gland and muscular activity, including vocal movements, is the only difference that we observe in cases where consciousness is present, Professor Watson proceeds to the assertion that consciousness *is* the sum total of the bodily differences in question.

(vi) *Thinking as Sub-vocal Talking.*—This rather startling conception is applied with considerable force to all kinds of so-called conscious processes. When, for example, we think, it is found that a number of muscles are being active in our larynxes. The activity of these muscles may be regarded as having for its object the unconscious formation of words which are not actually uttered. Thinking, then, is simply sub-vocal talking, involving as it does the same muscular activities as those which occur in talking, although these activities are not carried so far. Thus all modern books on psychology which exemplify this school of thought include chapters on what is called the language habit, which describe at some length the bodily movements which occur both when we are talking and when we are thinking but not talking. These movements can be brought under the response to stimulus formula of which simple examples have already been considered, and, as a consequence, thinking, and indeed all other mental activities, can be reduced to very complicated but nevertheless automatic responses to external situations.

We are, I think, entitled to ask whether there is not faulty reasoning here. We may demonstrate that consciousness, including what we call thought, is always accompanied by certain bodily movements, that these bodily movements are forms of response to external or internal stimuli, and that by suitable conditioning we may change the stimuli that provoke them; but this demonstration surely does not prove that consciousness *is* the bodily movements which accompany it. Similarly we may disprove the existence of consciousness as a separate constituent item in our mental make-up; we may show that it only

attaches to certain trains of activity, whether interpreted physiologically or psychologically, which we call desires, wishes, and so forth, and that these trains of activity may occur in all respects unchanged without being characterized by this quality or adjunct of consciousness; and we may infer that, therefore, consciousness is an unimportant, casual phenomenon, whose presence or absence makes no difference to the actual events which are occurring in our psychology. But this once again does not prove that consciousness is a myth; and, if consciousness is not a myth, mind is not a myth either. It is time, therefore, to change our method of approach, and to see what arguments can be adduced in favour of the belief in mind as something distinct from the body.

CHAPTER THREE

THE MIND AS DISTINCT FROM THE BODY

THE ALTERNATIVE HYPOTHESIS

I POINTED OUT in the first chapter that the issue between those who endeavour to interpret mind action in terms of body action, and those who contend for the unique, distinct, and in some sense independent status of mind is not capable of definite settlement. No actual refutation of the arguments advanced in the last chapter is, therefore, to be expected. The most that can be done is to suggest certain objections that can be and have been brought against the materialist position which has been outlined above, and at the same time to indicate a number of independent considerations which seem to demand a different kind of approach to psychology, and a different interpretation of its problems. This interpretation, to put it briefly, insists that a living organism is something over and above the matter of which its body is composed; that it is, in short, an expression of a principle of life, and that life is a force, stream, entity, spirit, call it what you will, that cannot be described or accounted for in material terms; that in human beings this principle of life expresses itself at the level of what is called mind; that this mind is distinct from both body and brain, and, so far from being a mere register of bodily occurrences, is able, acting on its own volition, to produce such occurrences, and that no account of mind action which is given in terms of brain action, gland activity or bodily responses to external stimuli can, therefore, be completely satisfactory. This is the view which in some form or other is held by those who find a materialist explanation of psychology unsatisfactory, and in this chapter we shall be concerned with the reasons for it.

BIOLOGICAL CONSIDERATIONS

Purposiveness.—Some of these reasons, and perhaps the most important, are derived in part from regions which lie outside the scope of psychology proper; they belong to biology, and are based on a consideration of the characteristics which all living beings are found to

possess in common. With regard to one of these "alleged"* characteristics of living organisms it is necessary to say a few words, since it constitutes a starting-point for the method of interpretation with which we shall be concerned in this chapter. The characteristic in question is that to which we give the name of purposiveness, and because of this characteristic it is said that any attempt to interpret the behaviour of living creatures in terms of material response to stimuli must inevitably break down. Purposiveness implies the capacity to be influenced by and to work for a purpose; this in its turn involves the apprehension, whether conscious or unconscious, of some object which lies in the future and which the purpose seeks to achieve; it therefore necessitates the existence of a mind. If, therefore, purposiveness is a true characteristic of living creatures, then we certainly have established a good starting-point for our "mental" approach to psychology.

What, therefore, is meant by saying that living creatures are purposive? Primarily, that in addition to those of their movements which may be interpreted as responses to existing situations, they also act in a way which seems to point to the existence of a spontaneous impulse or need to bring about some other situation which does not yet exist. This impulse or need is sometimes known as a conation; a good instance of the sort of thing that is meant is the impulse we feel to maintain the species by obtaining food or seeking a mate. The impulse is chiefly manifested in the efforts a living organism will make to overcome any obstacle which impedes the fulfilment of its instinctive need. It will try first one way of dealing with it and then another, as if it were impelled by some overmastering force which drove it forward to the accomplishment of a particular purpose. Thus the salmon, proceeding up stream, leaping over rocks and breasting the current in order to deposit her spawn in a particular place, is acting in a way which it is difficult to explain in terms of a response to external stimuli. An organism again will seek to preserve the trend of natural growth and development by which alone the purpose of its existence will be fulfilled; in its endeavour to reach and to maintain what we may call

*I insert the word "alleged" in order to indicate the controversial character of the subject. There is no doubt that it would be thought unsafe by many biologists to assume the existence of the characteristic in question, although I myself do not wish to deny it.

its natural state or condition, it is capable, if need arises, of changing or modifying its bodily structure. If you take the hydroid plant Antennularia and remove it from the flat surface to which it is accustomed to adhere, it will begin to proliferate long wavy roots or fibres in the effort to find something solid to grip, while everybody has heard of the crab's habit of growing a new leg in place of one that has been knocked off.

Activity of this kind seems difficult to explain on materialist lines as the response to a stimulus; it appears rather to be due to the presence of a living, creative impulse to develop in the face of any obstacle in a certain way. That a living organism works as a machine works, by reacting in the appropriate way to the appropriate stimulus, is admitted; all that is contended is that it acts in other ways as well, that these other activities depend not only upon the quality of stimulus received, but upon the intensity of the creature's conative impulse, and that the existence of the impulse is only explicable on the assumption that the creature is animated by the need to fulfil a purpose.

Foresight and Expectations.—When we apply this conclusion to human psychology, we are immediately struck by the fact that the individual not only exhibits in common with other organisms this characteristic of purposive behaviour, but is in many cases conscious of the nature of the purpose which inspires his behaviour. The man who studies in order to pass an examination is not only impelled by a push from behind; he is drawn forward by a pull from in front. This pull from in front can only become operative if he can be credited with the capacity to conceive the desirability of a certain state of affairs—namely, the passing of the examination, which does not yet exist; he shows, in other words, foresight and expectation. It is activities of this kind which seem most insistently to involve the assumption of a mind to do the foreseeing and expecting. In other words, the capacity to be influenced by events which lie in the future seems inexplicable on the stimulus-response basis; the *thought* of what does not exist may be allowed to influence the mind, but it is difficult to see how the non-existent can stimulate the body.

The explanation of our capacity for being influenced by the thought of events that do not yet exist, raises much the same difficulty as our undoubted responsiveness to events that have existed but do so no

longer, and it will be desirable to consider the problem first of all from this point of view.

The Influence of the Past.—It is clear in the first place that the influence of the past is continually affecting what happens in the present. Even the most distant events in my personal history exert their influence upon what I am thinking and wishing now. If I have been to New York and you have not, the casual mention of the words "New York" in our joint hearing will have an effect upon me very different from and much richer than that which it will have upon you: this is because of the different influences exerted upon our present selves by the different events that have occurred in our respective pasts, influences which, in my case, are much more various than in yours. The mere fact that I know how to hold my pen as I write, and cause it to trace the letters that form the words I want, is the unconscious effect of my having learned how to write in the past. The influence of the past is, therefore, all pervasive; it affects every single act and thought of our waking life.

The operation of this influence raises one of the most difficult questions in psychology; this is the question of the nature of memory, whether conscious, as in my memory of New York, or unconscious as in my memory of having learned to write. The problem of memory put very briefly is as follows: My act of remembering is an act which exists in the present; the event which I remember occurred in the past, and would appear, therefore, no longer to exist. But how can that which does not exist affect that which does exist? Now this problem, as I have already pointed out, is essentially the same as that raised by expectation. If I hear the beginnings of a tune that I have heard before, I may after the first few bars of it be able to continue it for myself; in other words, I shall know what is coming. But I am only able to do this in virtue of my unconscious memory of the past which conditions my expectation of the future; my knowing what is coming is, in fact, determined by my remembering what actually came.

It would not be difficult to show that all cases of expectation depend upon and involve, at least in part, acts of unconscious memory. If then we examine the theories of memory current in psychology, we may get some light on the problem which we are at present consider-

ing—namely, the problem of the distinct and independent existence of mind, which we found to be implied by expectation. There are roughly two types of theory, each of which is held in one or another of several different forms by psychologists.

THEORIES OF MEMORY

I. *Physiological.*—(*a*) The first, which gives a physiological account of memory, was put forward in the following form by a psychologist called Semon. What I am aware of when I appear to remember something is not the past occurrence which, as I say, I remember, but a present state or modification of my body. This present state or modification is called an engram, and is produced as follows: Let an organism which is in a state of equilibrium, which we will call condition (A), be subjected to any stimulus XY which excites it. When the excitement has subsided, the organism will settle down again to a state of equilibrium, but this second state (B) is not quite the same as the first state (A); the excitement, in other words, has left behind a continuing effect or trace on the organism, in virtue of which its general condition is different after the excitement is over from what it was before. This difference—the difference, that is, between the two states of equilibrium—is the engram. It is envisaged in physiological terms—Semon calls it some material alteration in the body of the organism—although what the precise effects on the nervous-system may be is not known.

So far we have considered the process in its simplest possible form. What happens in actual fact is not that an engram is produced by an isolated stimulus, but a whole complex of engrams results from the application of a number of associated stimuli. When some part of the original stimulus XY, whether X or Y, or any of the stimuli associated with XY recurs, it calls forth the whole complex of engrams produced by the original complex of associated stimuli. When this happens, we are said to remember the event from which the engram, or engram complex, results.

Putting this into psychological language—although we must be careful to remember that Semon's theory does not necessarily involve the existence of psychological entities such as consciousness—we may say that what we are aware of when we say we remember a past

event, is a present modification of our bodies which the past event has left behind.

(*b*) There is another way of interpreting memory from the physiological point of view which practically succeeds in dispensing with the intervention of consciousness or awareness altogether. It also eliminates the notion of specific physiological modifications or traces.

Let us suppose that we are expecting to meet somebody. Our feeling of expectation translated in terms of the nervous-system means that there is a special setting of the co-ordination or association* centres in the brain, in virtue of which we shall be more ready to pick out certain stimuli, those, namely, associated with the person expected, from the innumerable stimuli which at any given moment are clamouring for our attention, than to pick out others. Our nervous apparatus for the reception of stimuli is, in other words, set in a particular pattern and is predisposed to receive only what will fit into the pattern, just as a lock may be said to be set ready to receive a key. The feeling which we know as expectation is just this setting of the nervous centres to receive certain special kinds of stimuli. It is as if, to change our metaphor, they were tuned up to a particular pitch and were prepared to vibrate only to notes of the pitch in question.

Now let us apply this conception to the question of memory. If you hear the first few bars of a familiar tune, you are able to remember the rest. Why? Because the stimulus of the first few notes sets the co-ordination centres ready for the reception of the rest. What set the co-ordination centres in the first instance was the hearing of the tune on the first occasion on which it was heard; but, as on Semon's theory, when the stimulus of the tune recurs it is only necessary for a part of the stimulus to be applied in order to produce the whole set of reactions which on the first occasion followed the complex of stimuli constituted by the whole tune. The more often the stimulus is applied, the smaller the part of it required to produce the whole response. A habit is formed when the response follows so readily that a mere hint or shadow of the original stimulus is necessary to provoke it. Habit, therefore, is simply a special case of memory; when, having done certain things very often in the past, we remember them so well that the merest hint of any one of these things is able to

**See* p. 401.

set going, and to set going unconsciously, a complicated series of reactions which it previously required a whole succession of stimuli to provoke, we have formed a habit. Here then we get an explanation of memory and of habit in physiological terms. Memory is due to the persistent effect of past stimuli; this persistent effect being, in Professor Hering's words, "the peculiar attunement of the nervous-system in virtue of which it will give out today the same note that it gave out yesterday, if the strings be touched aright."

II. *Psychological.*—The ordinary psychological explanation of memory is on the following lines. An event which has happened to us does not, when it recedes into the past, leave no trace of itself behind; on the contrary, it makes an indelible impression on the individual who experiences it. This impression is not an alteration of the body, but is conceived to be an image or reflection in the mind. Every experience we have ever had is said to leave some image of itself in this way. These images, however, rapidly fade into the unconscious,* which may be regarded as a storehouse of past experiences, where they normally remain. When something occurs which resembles the event which originally left the image, it causes the image to rise into consciousness. We are then said to remember the past event, when what we are in fact thinking about is the *present mental image or reflection* of the past event.

CRITICISM OF THEORIES OF MEMORY

We were originally led to undertake this account of theories of memory, not only because memory as an important function of the mind is entitled in its own right to a description in a book on "The Mind and its Workings," but also because it was thought that an examination of the vexed questions that memory raises might reveal serious difficulties in the physiological interpretation of psychology with which we were concerned in the last chapter. It is now time to see what these difficulties are.

Let us begin with the psychological account of memory given in II above. Whatever may be the merits or demerits of the physiological theories of engrams and attuned nervous centres, it seems clear that the psychological image theory at any rate will not work.

**See* Chapter Five for an account of the unconscious.

(i) *The Image Theory.*—To begin with there is considerable doubt as to whether such things as images exist; many psychologists do, in fact, deny their existence. Apart, however, from this doubt, there is a more serious objection to the theory, and that is that images, even if they do exist, will not perform the function which they are said to perform. They are said to be copies or reflections of past events. But you cannot know that a copy is a copy unless you have the original to compare it with. If you see the face of a friend in the glass, you cannot tell that it is your friend's face and not the face of some other person, unless the face of your friend is already known to you, and not only known in a general sort of way, but present to your mind's eye at that particular moment, so that, comparing it with the image in the glass, you recognize the image as an image of your friend's face and of no other.

In order, therefore, that we may be in a position to recognize A as a copy of B, we must be aware both of A and of B. Now on the theory of images described above, we are said to know the present image but not the past event of which it is an image. But if we do not know the past event, how can we know that the present image represents it; if we do know the past event, if, in other words, the mind possesses the power of going back to the past and being directly aware of it, what is the purpose of evolving an image which is said to be like the past event, in order that the mind may be aware of that? But if memory can only be explained as a direct awareness of what is past, it quite certainly involves a mind. Mind may be credited with this mysterious power; body certainly cannot.

(ii) *The Engram Theory.*—How does this reasoning affect the physiological theories of memory? The salient feature of the physiological account of memory was that when any part of an original stimulus, or set of stimuli, was repeated, it tended to call forth the whole complex of reactions formerly provoked by the original stimulus or set of stimuli. Pursuing, therefore, their policy of interpreting psychology without introducing mental terms, these theories sought to identify the experience known as remembering with this repetition of a former set of bodily reactions, or (if we see no necessity for being quite so rigorous in our exclusion of mind) with the awareness of the repetition of these reactions. But if, as alleged, the reactions produced

by a recurrence of part of the original stimuli are literally the same as those originally provoked by the stimuli which constituted the remembered event, then remembering an event ought to be indistinguishable from experiencing it. But thinking of the pain I suffered yesterday at the dentist is quite indubitably not the same as experiencing it. It follows, therefore, that whatever memory is, it cannot be the occurrence of the same reactions (or the awareness of the same reactions) as those caused by the stimuli constituted by the event remembered. Applying this type of reasoning to Semon's view, we get the following results: Either the physiological modification resulting after the stimulus has ceased to operate, the engram, that is to say, of which we are said to be aware in memory, is the same as the response activity provoked by the original stimulus, or it is not. If it is the same, then being aware of an engram—that is to say, remembering an event—ought to be identical with the actual experience of the event, which it is not; if it is not, then it is difficult to see why the process of becoming aware of an engram, which is not the same as the response to the past event, should make us think, not of the engram, but of something which is different from the engram, namely, the past event.

The same type of objection applies to the physiological explanation of recognition. When you see a thing a second time and recognize it as something you have seen before, the feeling of recognition is, as we have seen, interpreted as due to a certain attunement of the nervous centres, in virtue of which they give off the same vibrations as they did on the occasion of the first experience of the thing in question. But if the response in terms of vibration is *really* the same, then seeing a thing a second time ought to feel exactly like seeing it the first time, in which event it would not be recognition. If it is not the same but a different response, why should its occurrence cause the feeling of recognition, which is involved by the reference to a past event at all? Why should it not simply cause us to think that we were seeing something new?

(iii) *Expectation.*—It will be remembered that the physiological account of memory sought at the same time to provide an explanation of the feeling of expectation. The nervous-system was set like a lock to receive the stimuli which conformed to a particular pattern. But

it is clear that the co-ordination centres could only assume this particular formation, could only evince this particular disposition to pick out certain stimuli rather than others, if, to speak in psychological terms, we know what to expect.

Now if we assume the existence of a mind credited with the power of anticipating future events, while admitting that this power may be in the last degree mysterious, we shall see no insoluble difficulty in supposing that we really do know what to expect. But if we dispense with a mental interpretation, or relegate the mind to the position of a mere register of bodily events, what explanation are we to give of this apparent knowledge? The physiological psychologist embraces it under his account of memory; the nervous centres, he tells us, are set in this particular form of arrangement because of past occurrences, with the result that, having heard a tune once, we have only to hear the first few bars of it again to be able to anticipate and supply the rest.

The view might account for our ability to anticipate events which are exactly like those which have already happened; but how can it explain the expectation of a completely new experience? If the experience is really novel there can have been no past events of a similar character to set the lock of the nervous system to receive the new key. Yet there is no doubt that we can have a feeling of expectation of something which, though dimly envisaged, is yet felt to be unprecedented. We may say, then, that in the present state of our knowledge it seems impossible to account for those of our feelings which relate to events which have still to occur, unless we are prepared to postulate the existence of something which is not material and which is credited with powers other than material powers.

We have spoken so far of purpose and expectation, and our conclusions seem to be that if feelings of expectation and the capacity to act purposively really are, as they seem to be, characteristics of the human being, then no purely physiological account of his psychology will fit the facts. How does this conclusion apply to the emotions? Some emotions—as, for example, the emotion of dread—also refer to the future. Can we, then, accept the account of emotion given in the last chapter?

The Emotions.—An emotion we there saw was interpreted as our

consciousness or awareness of a physiological event. Our bodies are stimulated by a perception of a ghost or a tiger; the result is a series of bodily changes of a kind tending to facilitate flight; our awareness of these changes is the emotion of fear. This account, plausible enough when a physical stimulus of some sort is actually present, seems to break down in the absence of such a stimulus. Let us suppose that I sit in my chair and think of an audience of a hundred psychologists whom I am to address next week; let us also suppose that, as I have every right to do, I feel nervous and agitated. What is the physical stimulus here? The meeting of psychologists does not yet exist; I may, therefore, be able to think of it, but I certainly cannot experience it as a physical stimulus. Is it, then, the chair in which I am sitting? This scarcely seems credible.

In cases of this kind, if we are still to regard the physiological changes as being the cause of the feeling of emotion, it rather looks as though the mental apprehension of the coming event must be the cause of the physiological changes. Mind, in other words, so far from being the mere reflection of material events, seems here to produce them. But there is a further reason for doubting the account of emotion given in the last chapter.

While the thought of lecturing to a hundred psychologists may cause dread, the thought of lecturing to a hundred students may cause pleasure. Now the difference between thinking of a hundred psychologists and thinking of a hundred students is a difference between two acts of experience, which seems to be a real and important difference. But how are we to envisage such a difference in terms of the nervous-system? Is there one pattern of the nervous centres representing the response to the stimulus constituted by the future meeting (or possibly by a past and remembered meeting) of a hundred psychologists, and another which is caused by a future meeting of a hundred students, and yet another by a future meeting of ninety-nine students, and so on for every different object of which the thought can cause a slightly different emotion? This seems to involve an almost inconceivable complexity on the part of the nervous-system.

Let me try to state the point in another way. The emotion of fear is said to be the mental awareness of excretions by the adrenal glands. Now let us suppose that I am frightened, and let us assume that my

fear is the consciousness of the fact that these glands are discharging a certain amount of fluid, which we may represent by x. If I am twice as frightened, the amount of discharge will be 2x, and if half as frightened $\frac{1}{2}$x. But fear shades by imperceptible degrees into a number of allied but qualitatively different emotions, such as repulsion, horror, disgust. What are the physiological equivalents for these? Not 2x or $\frac{1}{2}$x, since these are already earmarked for greater or less quantities of fear proper. We must, then, postulate the existence of some other gland whose excretions can be held to provoke the qualitatively different feelings associated with these emotions. This is bad enough, but it is not the worst. Fear is not absolutely distinct from disgust; it passes imperceptibly into disgust through a number of intermediate shades of emotion which partake partly of fear and partly of disgust, but are qualitatively different from either. Since excretions from any particular gland can only be made to account for a greater or less quantity of the same *kind* of emotion, we shall have to postulate a separate gland for each of these qualitatively different states. Now the number of intermediate shades between one kind of emotion and another is infinite; yet, since the body is spatially limited, the number of corresponding glands must be finite. Therefore, the attempt to explain emotion as awareness of gland action, or indeed bodily action of any kind, seems to break down.

It is not contended that this type of reasoning is necessarily conclusive. It does, however, show the difficulty of trying to explain the infinite variety of mental life in terms of bodily changes. The number of thoughts of which a human being is capable is infinite; so too is the number of different feelings which he may experience; but the number of changes of which our bodies are capable, though exceedingly large—the complexity of the nervous-system still baffles investigation—is necessarily restricted by the spatial limitation of the body and the number of its organs.

We conclude, then, from this study of memory, of expectation and of the emotions, that there are at least some mental facts which, though accompanied by and involving bodily facts, cannot be wholly explained in terms of them. The mind does not merely reflect the body; it outruns it, and in so doing initiates thoughts and actions on its own account of which the body is merely the registering accom-

paniment. Let us now consider some further evidence pointing in the same direction.

THE APPREHENSION OF MEANING

An important fact about our mental life is that we are capable of appreciating meaning. A statement of fact written on a piece of paper is, so far as its material content is concerned, merely a number of black marks inscribed on a white background. Considered, then, as a collection of visual, physical stimuli, it is comparatively unimportant; what is important is the meaning which is attached to these marks. If they inform us, for example, that we have received a legacy of ten thousand pounds it is not the black marks on the white background, but the meaning they convey that effects a disturbance in our emotional life, sufficiently profound to keep us awake all night. Now the meaning of the marks is obviously not a physical stimulus; it is something immaterial. How, then, is its effect to be explained in terms of bodily responses to physical stimuli, which the mind merely registers? Let us take one or two further examples in order to present the difficulty in a concrete form.

Let us suppose that I am a geometrician and am thinking about the properties of a triangle. As I do not wish at this point to enter into the vexed question of whether *some* physical stimulus is or is not necessary to initiate every chain of reasoning, we will assume that in this case there was a physical stimulus—it may have been a chance remark about Euclid, or the appearance of a red triangular road signpost while I am driving a car—a stimulus which we will call X, which prompted me to embark upon the train of speculations about the triangle. My reasoning proceeds until I arrive at a conclusion, which takes the form of a geometrical proposition expressed in a formula. I carry this formula in my head for a number of days and presently write it down. In due course I write a book, setting forth my formula and giving an account of the reasoning which led me to it. The book is read and understood by A. Presently it is translated into French, and is read and understood by B. Later still, I deliver a lecture on the subject which is heard and understood by C. As A, B and C have each of them understood my formula and the reasoning upon which it is based, we may say that the reasoning process has had

for them the same meaning throughout. If it had not, they would not all have reached the same conclusion and understood the same thing by it. Yet in each of the four cases the sensory stimulus was different; for myself it was X, for A it was a number of black marks on a white background, for B a number of different black marks on a white background, and for C a number of vibrations in the atmosphere impinging upon his ear-drums. It seems incredible that all these different stimuli should have been able to produce a consciousness of the same meaning, if our respective reactions to them were confined to physical responses (which must in each case have been different) which were subsequently reflected in our minds by a process of mental registration of the different responses. The stimuli being different, the intervention of something possessed of the capacity to grasp the *common* element among these physically different entities alone seems able to account for the facts; but the common element is the meaning, which is immaterial and can be grasped, therefore, only by a mind.

Let us take another example instanced by Professor McDougall: A man receives a telegram which says, "Your son is dead." The visual physical stimulus here is, as before, a collection of black marks on an orange field. The reaction experienced in terms of his bodily behaviour may take the form of a complete cessation of all those symptoms usually associated with life—that is to say, he may faint. When he recovers consciousness his thoughts and actions throughout the whole of the remainder of his life may be completely changed. Now that all these complicated reactions are not constituted by and do not even spring from a response to the *physical* stimulus, may be seen by comparing the reactions of an acquaintance who reads the telegram, and so subjects himself to the same stimulus. Moreover, the omission of a single letter, converting the telegram into "Our son is dead," would cause none of the reactions just described, but might result at most in the writing of a polite letter of condolence. The independence of the bodily reactions of the physical stimuli actually presented is in these cases very marked, and, unless we are to introduce conceptions such as the intellectual apprehension of the *meaning* of the marks, it seems impossible to explain their effect. Yet such a conception again involves the active intervention of mind.

Synthesizing Power of Mind.—This conclusion is reinforced by what we may call the synthesizing power of mind. Synthesizing means putting together, and one of the most remarkable powers that we possess is that of taking a number of isolated sensations and forming them into a whole. We shall have occasion to return to this point at greater length in connexion with our account of sensation in the next chapter. For the present, we will content ourselves with giving one or two examples of mental synthesis.

Let us consider for a moment the cause of æsthetic appreciation. The notes of a symphony considered separately consist merely of vibrations in the atmosphere. Each note may, when sounded in isolation, produce a pleasant sensation, and as one note is struck after another we get a sequence of pleasant sensations. But although this is a sufficient description of the symphony considered as a collection of material events, and of our reactions to these events considered merely in terms of sensations, it is quite clear that we normally think of a symphony as being something more than this. We think of it in fact as a whole, and it is as a whole that it gives what is called æsthetic pleasure. Now in thinking of the symphony in this way our mind is going beyond the mere sequence of pleasant sensations which its individual notes produce, and putting them together into some sort of pattern. If the notes were arranged in a different order, although the actual vibrations which impinged upon our senses would be the same, the pleasurable æsthetic effect would be destroyed.

It seems to follow that our pleasure in a symphony cannot be wholly accounted for, although it may depend upon our physical responses to the stimuli of the individual notes; in order to obtain æsthetic pleasure we must somehow be able to perceive it as more than the sum total of the individual notes—that is, as a whole pattern or arrangement. The pleasure ceases when the *wholeness* of the object perceived is destroyed, as it is, for example, by the transposition of certain notes. We may compare the difference between the physical sensations which are our responses to the visual stimuli of the colours and canvas of which a picture is composed, with our synthesized perception of a picture as a work of art.

We must conclude, then, that we possess the power of realizing external objects not merely as collections of physical stimuli, which

of course they are, but as wholes in which the actual sensory elements are combined to form a single object of a higher order. This faculty of combining or putting together seems to involve the existence not only of a mind, but of a mind of an active creative type, which is able to go out beyond the raw material afforded by our bodily sensations, and to apprehend ideal objects as wholes which are more than the collection of physical events which compose their constituent parts.

SUMMARY OF ARGUMENT

The conclusion to which the arguments of this chapter appear to point is that in addition to the body and brain, the composition of the living organism includes an immaterial element which we call mind; that this element, although it is in very close association with the brain, is more than a mere glow or halo surrounding the cerebral structure, the function of which is confined to reflecting the events occurring in that structure; that on the contrary, it is in some sense independent of the brain, and in virtue of its independence is able in part to direct and control the material constituents of the body, using them to carry out its purposes in relation to the external world of objects, much as a driver will make use of the mechanism of his motor car. Mind so conceived is an active, dynamic, synthesizing force; it goes out beyond the sensations provided by external stimuli and arranges them into patterns, and it seems to be capable on occasion of acting without the provocation of bodily stimuli to set it in motion. It is, in other words, creative—that is, it carries on activities which even the greatest conceivable extension of our physiological knowledge would not enable us to infer from observing the brain. How, then, are we to conceive of the relationship of the mind to the brain?

An actor in a play of Shakespeare not only speaks words, but makes gestures, so that if you were completely deaf you would still be able to infer something of what the play was about from seeing the gestures. It is obvious, however, that there is much more in the play than the pantomime of the players. There are, for example, the words, the characters, the plot, and the poetry. Now to use a simile of the philosopher Bergson, the brain is the organ of pantomime. If you

were to observe a man's brain you would know just as much of his thoughts as found vent in gestures. You would know, in other words, all that his thoughts imply in the way of actions or the beginnings of actions,* but the thoughts themselves would escape you just as the words and meaning of the play would escape the deaf spectator. This is what is meant by saying that the mind overflows the brain. If our knowledge of both psychology and physiology were perfect, we should be able to describe the movements of the brain without observing it, provided we had complete understanding of a man's state of mind; but we should not from the most minute and thorough inspection of the brain be able to tell what the man was thinking, since just as one gesture of the actor may stand for many different thoughts, so one state of the brain may represent any one of a host of states of mind.

*Among the beginnings of actions may be mentioned those movements of the larynx which are involved in talking.

CHAPTER FOUR

THE MIND AS AN ACTIVITY

THE FACULTY PSYCHOLOGY

SO FAR, WE have said very little about a number of questions that bulk largely in many books on psychology, more particularly in the older ones. The subjects with which psychologists used to concern themselves were, until the last few years, very different from those which have occupied our attention up to the present. The older psychologists would discuss at length such questions as the number and the nature of the instincts, the relationship of instinct to reason, the difference between sensation and perception, and whether there were in addition to the instincts and the emotions such things as sentiments and dispositions. Such discussions are now often referred to as belonging to what is called "academic psychology." Our reasons for not introducing them at an earlier stage and devoting to them a larger share of space are twofold:—

1. It did not seem desirable to discuss the nature of mental qualities and faculties until we had satisfied ourselves that there was a mind to exhibit qualities and to possess faculties. It is necessary to establish the existence of a thing before proceeding to inquire what sort of thing it is. The study of the relationship between mind and body has tended, moreover, to throw a good deal of light upon the nature of the entities related, and we have already in the course of our inquiry been obliged to examine incidentally a number of important mental functions such as the memory and the emotions.

2. In the second place, even if we provisionally assume the existence of mind, as something distinct from the body, to have been established, we know far too little about its character to pronounce with any certainty upon the number and nature of its faculties. The controversial and experimental character of modern psychology cannot too often be emphasized, and one of the points upon which controversy largely turns is, whether the mind possesses attributes which are properly to be called faculties or states at all.

Now the older psychologists were content to discuss the instincts and the reason much as a physiologist would deal with the heart or

the leg. I do not mean to say that when they affirmed that there were, for example, seven instincts they meant that the mind had instincts in the sense in which the body has toes; but they were nevertheless inclined to write about instincts and sentiments and so forth as if they were distinct things which could be segregated and catalogued for the purposes of discussion like toes. More recent work has, as we shall see, thrown considerable doubt upon these older conceptions of the mind. The mind is no longer regarded as a bundle of faculties or as a thing possessing a number of attributes, any one or more of which may be in play at a given moment, but rather as a stream or force which from moment to moment gives off fresh reflections, as it flows at different speeds. According as the speed and direction of the flow vary, so will a man be feeling instinctively or reasoning. A faculty, then, is merely the activity of the whole mind as evidenced at any given moment.

Nevertheless, it is necessary to say something about the questions which have occupied so large a place in traditional psychology, if only to throw the newer conception more clearly into relief.

SENSATION AND PERCEPTION

It is extremely important in the first place that we should get a right conception of the sort of thing that a mind is, before we enter into a detailed examination of its characteristics, especially as a right conception is not to be attained without some imaginative effort. We are so accustomed to thinking in terms of things which are made up of parts, that it is very difficult to avoid picturing the mind as a number of mental states which are themselves built up out of component parts as a house is built of bricks. Many people have so regarded the mind, and a large part of traditional psychology has been devoted to showing that all mental states were made up of two sorts of bricks—namely, sensations and images.

It is important, therefore, to realize that there is no evidence for the existence of such mental bricks, whether conceived as states or faculties. Such terms as the will, the instincts, the reason, and so forth, though useful enough for the purpose of describing our experiences, do not correspond with any real existents; they are not facts, but hypotheses. And in saying that they are not facts, but hypotheses,

what I mean is that they are never met with in actual experience. Sensations, for example, which used to be regarded as the core of our experience, the raw material supplied to us by the outside world, out of which the whole structure of our mental and emotional life was built, are mere figments. Nobody has ever met with a sensation for the simple reason that any apparent sensation which we choose to inspect turns out to be not a mere passive experiencing of an external stimulus, but a highly complex affair to which the mind has already made considerable contributions.

The influence of past experience, for example, as pointed out in the last chapter, enters into and affects all our present experience of the external world. A chair wears to a civilized man an entirely different appearance from that which it presents to a savage who sees it for the first time. The latter probably sees the chair not as a chair at all but as a couple of legs and a back, which is all that we ordinarily observe when we imagine ourselves to be seeing a chair. Again, a piece of modern music actually sounds differently to the habitual concert-goer and to the Oriental, as is evidenced by the story of the Chinaman who went to the Queen's Hall and thought that the tuning up was the concert. Each experiences the same stimuli, but the past experience of each distorts, selects and contributes to what is actually heard, so that the resultant products are different. The mind, in fact, rushes in to embrace the actual stimulus received, and to clothe it with elements culled from its past experience, with the result that nobody has ever met a stimulus naked.

A good example of the activity of the mind in working up the impressions received from without is afforded by the experience of learning to draw. It is then found that most of what we think we see is not seen at all, with the result that the young artist is chiefly employed in learning to unlearn the view of the world which conventional experience has caused him to adopt, by stripping away, so far as he can, the accretions with which his mind has invested the thing actually seen. Even so, however, he does not succeed in arriving at a pure sensation. Another striking example of the same process is afforded by the experience of going to a theatre in a foreign country, where the language, although known to us, is understood with difficulty. Our hearing seems to be strangely dulled, and, as a consequence,

it is found that it is necessary to sit much nearer to the stage than we are accustomed to do in our own country. The reason is that when we listen to someone speaking our own tongue, the proportion of the words he utters that we actually hear is comparatively small, the mind supplying the rest by guesswork. We expect him to say certain things on the analogy of past experience, and as a consequence we have only to hear a very little for our minds to take the cue and add the rest. This activity of the mind does not, of course, occur when the language is unfamiliar, and we accordingly find it necessary to hear more because we supply less.

Optical illusions, again, illustrate our propensity to see what we expect to see, and it is an interesting fact that books in Latin, Greek, and still more in Hebrew, are better printed than English books, because proof readers, having no expectation of what is coming, have to depend upon correspondence with the manuscript to ensure accuracy instead of jumping to conclusions on the basis of what they expect.

It is these inevitable mental additions to what is seen and heard which modern psychology has in mind when it denies the existence of a pure sensation, because of the constant intervention of the mind's activity. A sensation invested in this way with matter drawn from past experience is called a perception, and what we are asserting is that in the long run all sensations are perceptions. It is now generally agreed among psychologists that, since the sensational core of perception is elaborated by the mind's activity, we never know anything as it really is, a reflection which has been the starting-point of many systems of philosophy.

What we are concerned with here, however, is the conception of the activity of mind, in virtue of which the bare sensation is non-existent.

Nevertheless, a sensation is a useful tool to work with, when we are trying to analyse our experience to find out what is its nature, and, like the intelligence, the will and the instincts, continues to be employed for want of a better term. Bearing in mind, however, the fact that the mind is not a thing but an activity, it is clear that we ought to describe its movements in terms of stresses, currents, energies and flows, using the language of electricity rather than that applicable to

ordinary static things. Perhaps psychology will one day employ such a vocabulary. Meanwhile, for want of a better one, we must continue to speak of the instincts, the reason and the will, and with this preliminary word of caution we may proceed to indicate some of the theories that psychologists have held in regard to them.

THE INSTINCTS

There is controversy both as to the nature and also as to the number of the instincts. As a rough general account, which, so far as possible, avoids controversial issues, we may say that every organism is found to begin life with a peculiar and individual psychological endowment; whether this is or is not completely inherited is a question into which we cannot here enter. This chiefly expresses itself in the way in which it behaves in the different situations in which it finds itself. The ant, for example, will behave differently in a particular situation from a man. Faced with this difference, we are accustomed to say *in partial explanation* of it that the instincts of the man and of the ant are different. It is further necessary, in order that behaviour should be classed as instinctive, that it should not have been learned, and should manifest itself in some form or other at a very early stage of the creature's existence. Thus the ant, which exhibits more unlearned forms of activity than the human being, is said to act very largely, if not entirely, upon instinct. In human beings and in most animals so called instinctive activities are chiefly manifested in relation to the fulfilment of certain fundamental needs. Of these needs the most important are the needs for food, sex and society. If a man does not have food, he dies; if he does not reproduce the species, he dies by proxy, seeing that, as Samuel Butler pointed out, he lives on in the person of his offspring; the infant who is deprived of society follows suit and dies, too; and the adult on a desert island may quickly go mad. All human beings exhibit activity of a kind designed to allay these fundamental needs, and they do so without being taught. Therefore, these needs may be called instinctive.

From the fundamental needs spring derivative needs. Thus in order to obtain food, it has usually been necessary to move about, the need for food tending to remain unsatisfied unless the individual literally took steps to satisfy it. Hence a derivative need for movement

arises, from which springs an objection to sedentary occupations. It scarcely seems, however, that our aversion to sitting still for too long can be called instinctive in the same sense as our need for food.

The above constitutes what may be called a moderate general account of the nature of instinct with which few psychologists would wish to quarrel. It will, in particular, be noticed that it avoids postulating the existence of an instinct as a distinct faculty or entity, and speaks of allaying instinctive activity or instinctive needs. This is an advantage in that it enables us to observe the injunction against treating hypotheses as facts made earlier in the chapter.

Many accounts of instinct, however, go far beyond this. Freud, for example, reduces all activity of the type known as instinctive to the expression of one or other of two fundamental desires, which he calls the ego instinct, which is concerned with the preservation of the individual, and the sex instinct, which is responsible for the reproduction of the species.

McDougall's View of Instinct.—The most celebrated view of instinct is, however, that of the late Professor McDougall. It occupies a rather curious position midway between the physiological interpretation of psychology illustrated in the second chapter, and the position of those who insist on the independent and autonomous status of mind. On the one hand it disclaims the materialism of those who hold that psychological states are mere reflections of bodily processes, while refusing on the other to vindicate the freedom of the mind in the sense in which most of those who reject the materialist view have wished to assert it.

(*a*) Professor McDougall begins by defining an instinct as "an inherited or innate psycho-physical disposition, which determines its possessor to perceive, and to pay attention to, objects of a certain class, to experience an emotional excitement of a particular quality upon perceiving such an object, and to act in regard to it in a particular manner, or, at least, to experience an impulse to such action." This definition amounts in effect to a denial of the materialist basis of psychology, since it postulates the existence of an instinctive desire to action which is not necessarily preceded by and dependent upon a physiological occurrence.

As to the number of instincts so defined Professor McDougall's

view has varied. In *Social Psychology*, published in 1908, he contended for the existence of seven primary instincts as being sufficient to account for our emotional life. Other instincts were regarded as blends of or derivations from these primary seven. In his *Outline of Psychology*, published in 1923, however, the number of primary instincts has increased to fourteen. A distinctive feature of McDougall's view is his association with each primary instinct of a special and unique emotion. He further contends that the instinct and the emotion associated with it are indissolubly bound together as forms of experience, so that whenever we act instinctively we feel emotionally as well. Each instinct, he says, "no matter how brought into play, is accompanied by its own peculiar quality of experience which may be called a primary emotion." There are, therefore, fourteen primary emotions.

Examples of primary instincts and their emotional equivalents are:

Instinct.	*Emotional Quality.*
Instinct of escape (of self preservation, of avoidance, danger instinct).	Fear (terror, fright, alarm, trepidation).
Pairing (mating, reproduction, sexual).	Lust (sexual emotion or excitement).
Social or gregarious instinct.	Feeling of loneliness, of isolation, nostalgia.

McDougall recognizes in addition to the primary emotions the existence of certain secondary or blended emotions which are made up of blends of one or more primary emotions. Examples of blended emotions are horror, awe and gratitude, and certain derived emotions, such as joy, anxiety, despair. These latter are experienced as the result either of the obstruction or of the facilitation of the course of activities prompted by the primary instincts.

Some writers hold that in addition to our instincts our psychology contains factors known as sentiments. A sentiment is formed by a group of instincts and emotions which are organized round a particular object or idea, love and hate being typical sentiments. The conception of the sentiments which has been popularized by the

psychologist, Dr. A. F. Shand, is important in connexion with the notion of character. A man's character, in the ordinary sense of the word, may be thought of as the system of all his different sentiments.

INSTINCT AND REASON

Before we proceed to comment on this scheme, it will be convenient to say something of McDougall's views on the relationship between instinct and reason. These are important since they result in effect in a denial of the freedom and spontaneity of mental processes. McDougall only rescues our minds from servitude to our bodies in order to enslave them to our instincts.

This result follows from his assertion that all our activities, of whatever kind, are instinctive in origin. "The instincts," he says, "are the prime movers of all human activity; by the conative or impulsive force of some instinct every train of thought, however cold and passionless it may seem, is borne along towards its end . . . all the complex intellectual apparatus of the most highly developed mind is but the instrument by which these impulses seek their satisfaction. . . . Take away these instinctive dispositions with their powerful mechanisms, and the organism would become incapable of activity of any kind; it would be inert and motionless like a wonderful piece of clockwork whose mainspring had been removed."

We are all familiar with that somewhat cynical view of human motive which insists on regarding the intellect as the mere handmaid of our desires, whose function is confined to evolving the best method of obtaining satisfaction for our instinctive needs. As Aristotle remarked long ago, it is desire which sets the ends of our actions, and it is the business of reason, by which he meant the practical reason, to plan the steps by means of which these ends may be realized.

Reason, in other words, cannot accomplish anything by itself; it must be prompted by a preceding desire before it begins to operate; it is the engine of the ego and desire is the steam which makes it go.

Now it would be easy to show, and many writers are fond of showing, that the superiority of the savage to the animal and of the civilized man to the savage is to be found precisely in his greater power of giving effect to his desires. This greater power he possesses in virtue of the greater efficiency of the tool which he has evolved—

that is to say, his reason; it furnishes him not only with justifications for what he instinctively wishes to do, but with arguments for what he instinctively wishes to believe. Thus all civilized nations are enabled to persuade themselves that they are in the right when they wish to make war, and individuals comfort themselves with the belief that they are performing a salutary duty when they wish to make themselves unpleasant. The savage, not being so efficient in the use of reason, does not feel the same need of moral justification, and is, therefore, able to indulge his instincts without being under the necessity of proving himself either a dupe or a hypocrite.

Now it is precisely this view of reason, as a faculty which has been evolved to find a means of satisfaction for our instincts, that is countenanced, although not explicitly advocated, by McDougall's view of instinct and by many schools of modern psychology.

THE QUESTION OF FREEWILL

By insisting that reason cannot initiate anything, this view deprives us of the power of freewill. It is true that our reason is set going by our instincts, and that these instincts really are ours; but it is equally true that on this view we can neither give an account of them nor can we control them.

It is usually held that within limits we can say that we will act like this or act like that, although it is agreed that we cannot say that we will feel like this or feel like that. Our instinctive needs and instinctive reactions are not, in other words, within our control; indeed, they often embarrass us by occurring in opposition to what we know to be our interests; for our actions, however, we *are*, it is thought, responsible. But can we on McDougall's theory even say that we will act like this or act like that? Most people believe that in addition to the instincts and the desires that spring from our instinctive needs, we possess what is called a will, in virtue of which we are enabled to repress any instinct or desire prompting us to activities which are repugnant to our moral sense. This process is known as resisting temptation. In order, however, that it may be effective, it is necessary that the will should be able to act freely. Now can we, on McDougall's view, claim for it the capacity for spontaneous action? It scarcely seems so.

There is considerable controversy over the nature of the will, into which we have not space to enter here; speaking generally, however, we may say that it must be either rational or else instinctive in character. If it is instinctive in character, an instinct, to use the term in a wide sense, whose function it is to ally itself with reason with the object of keeping in check the other instincts, then its success or failure on any particular occasion will depend upon the respective strengths of the will and of the instinct which the will is seeking to suppress. The case, in short, is one of two warring instincts. If the instinct to suppress is the stronger, we resist the temptation; if the weaker, we yield. Since, however, we cannot be held responsible for the comparative strengths of the two instincts, we cannot be held morally accountable whichever way the issue goes. If, on the other hand, the will is rational, we must, on McDougall's view, conclude that it can only begin to operate if there is an instinct behind it. If it requires an instinct to cause us to think about the differential calculus, it will be no less the driving force of instinct which causes us to restrain ourselves from lying, from boasting, or from stealing. And since, whatever views we may hold with regard to the freedom of the will on general grounds, the prompting of our instincts is usually regarded as a matter outside our purview, the rational self-control on which we pride ourselves as the basis of a good or strong character must, like a good eye at games or a placid temperament, be consigned to the category of those attributes which we possess if we are lucky, and lack if we are not. It is not the existence of what is called self-control which is denied, but our responsibility for its exercise. On this view, then, ethics and all that ethics implies is a fiction; it is rationalization of instinctive processes by beings whose vanity is gratified by the belief that they are moral, but it is a rationalization which is itself undertaken at the imperious behest of instinct.

CRITICISM OF THE FACULTY PSYCHOLOGY

But is it after all necessary to accept this view? In order to answer this question, let us begin with McDougall's theory of instinct upon which it is founded. How far, it may be asked, are we justified in treating the instincts given in McDougall's list as distinct faculties at all? We spoke above of certain needs which seem common to human

beings, the needs for food, for sex, and for society; these, we said, were fundamental in the sense that failure to satisfy them involved the death, or at least the serious impairment of the individual. Now these needs have a further and equally important characteristic; they tend to recur at regular periods as a result of internal disturbances which are probably largely physiological in character. For this reason we may perhaps regard as instinctive the activities to which they prompt the individual, in the sense that these activities, being of the nature of automatic response to internal stimuli, are outside our conscious control. We can give no account of why we become hungry; we just do.

If, then, we may justifiably regard the activity springing from this type of need as instinctive, in what sense can we apply the word "instinct" to the items on McDougall's list? The instincts to combat or to construction (two instincts which figure on the list) are not periodically recurrent, nor does the failure to satisfy them lead to serious harm to the individual. They do not, therefore, seem to be fundamental facts of our nature in the sense in which the need for food or sex is fundamental, and they are far from being universal. It is probable, then, that we should be nearer the truth in regarding them merely as types of response to particular situations, or as characteristics of the activity which we call life of which we can give no account whatever, except to note their prevalence in some individuals and their absence in others. We are moving here in the direction of regarding instincts, not as separate mental units, but as characteristics of certain types of behaviour, or, if the metaphor be preferred, as facets of a general stream of life.

It is in the same direction that we must look for a correct account of the relationship of instinct and reason. The difficulties of McDougall's theory arise from his treatment of reason and instinct as if they were two distinct things. If they were, in fact, distinct, then there would be good grounds for supposing that reason was dependent on the promptings of instinct, since in depriving reason of any admixture of the driving force of instinct we should by definition have rendered it powerless to act on its own account. But the mind is not a bundle of distinct faculties, and there is consequently no such thing as instinct uninformed by reason, or as reason uninspired by

instinct. It is, of course, quite true that in one sense we never do anything unless we want to; but that does not mean that when we want, for example, to do mathematical problems our wanting is one thing and the rational activity to which it prompts us is another. A better way of putting it would be to say that in all our activities we are impelled by a drive of impulses which express themselves sometimes in behaviour which is called instinctive, as when we seek a mate, sometimes, as in the case of the mathematical problem, in what are called intellectual operations, but never in behaviour which is either completely instinctive or completely rational. We may say if we like that the sex instinct normally finds satisfaction through non-rational activities, and the instinct of intellectual curiosity through rational activities, but both reason and instinct are present in each case, because each is merely a different current of the same stream.

THE ORGANISM AS A CO-OPERATING PARTNERSHIP

Let me try to make this important point clearer by taking an illustration from physiology. It is known that the phagocytes or white corpuscles in the blood co-operate with the rest of the organism by surrounding and digesting intruding bacteria. This beneficent activity they carry out not mechanically and under compulsion, but as an army of volunteers, each of which is merely obeying its own spontaneous impulse to co-operate with the rest. "Each phagocyte indeed," to quote Professor Graham Wallas, "hunts and digests nearly as independently as if it were an isolated inhabitant of a warm tropical sea. A man's hair co-operates with the rest of his organism by protecting his brain from blows and sudden changes of temperature; but it may go on growing though the man has ceased to live. His epithelial cells may begin at any moment to proliferate independently and so cause death by cancer." Thus the body may be regarded as a collection of semi-autonomous units, each of which is endowed with the power of independent action. The process of bodily evolution is a process by which these units so learn to co-operate with one another, that instead of acting like an undisciplined rabble, they produce the appearance of a homogeneous unit. "The aim of the evolutionary development of the central nervous-system," in Dr. Head's words, "is to integrate its diverse and contradictory reactions, so as to produce

a coherent result adapted to the welfare of the organism as a whole." In other words, the body is like an army of volunteers working together for a common end; the more they work together, the more successful the functioning of the body.

What is significant in this view of the body is the conception of the co-operating parts of the organism as each possessing its own drive. Carry over the notion into psychology, and instead of regarding the mind as a collection of faculties, some of which possess the power of spontaneous initiation while others do not, you will come to think of it, on the analogy of the body, as a set of co-operating but autonomous elements, each of which is endowed with the capacity to initiate mental activity on its own account. Thought, then, does not require the driving force of instinct to set it in motion; it is driven by an impulse which is life itself, an impulse of which instinct is but another manifestation. So far so good; but the analogy must not be pressed too far, for, taken literally, it would require us to suppose that there are distinct elements or units in the mind, just as there are distinct phagocytes in the blood, which is the very conception against which we have been arguing. Having utilized it, therefore, in order to borrow the notion of an all-pervading impulse of life which animates each part or aspect, let us concentrate our attention on one such aspect, the reason, and ask ourselves whether a reason which is credited with the capacity to function on its own initiative can properly be regarded as reason at all. Certainly it is no longer reason conceived, as it is in McDougall's view, as a mere instrument; rather, it is reason blended with instinct in an indissoluble unity, which defies any attempt to separate it into parts. Like concave and convex, reason and instinct may be usefully distinguished for the purposes of classification as different aspects in the whole to which they both belong; but to treat them as separate elements, one of which stimulates or employs the other, implies a radically false conception.

PERCEPTION AND THOUGHT

This point of view may usefully be applied to the consideration of a question which is often discussed by psychologists, the question, namely, of the relation between perception and thought. We have already referred to the relationship between perception and sensation,

and pointed out that, inasmuch as some mental contribution from ourselves is present as an ingredient in every alleged case of sensation, there is, in fact, no such thing as a sensation proper. But a further stage of mental activity is usually supposed to supervene upon perception in order to constitute what is called thought.

Thought is the faculty of interpreting our perceptions, of linking them with other perceptions, of finding, in other words, a meaning for them. We have already mentioned this active function of the mind in the last chapter in connexion with the apprehension of meaning. Our object, then, was to point out that this activity was inexplicable on the basis of the materialist view of psychology. Our present concern is different; it is to show that just as instinct was found to be indistinguishable from reason, and just as sensation was observed to shade by imperceptible degrees into perception, to be continuous with it and inseparable from it, so is perception equally continuous with and inseparable from thinking. Many philosophers have held that the mind is fitted up with a sort of manipulating apparatus which gets to work upon whatever material is presented to it, breaking it up and transforming it into the objects about which we think. If, to take an analogy, I had been born with a pair of blue spectacles permanently affixed to my nose, I should see everything blue. This would not, of course, mean that the things I saw were blue, but simply that the blue appearance was imposed upon them by me as a necessary condition of my seeing them at all. Now it has often been argued that this mental apparatus to which I have referred is like the spectacles, or rather it is like several pairs of them acting together, in that it takes hold of the data afforded me by my perceptions, so that, by the mere process of becoming aware of them, I do, in fact, imperceptibly alter them. This view of the activity of the mind in perception was advocated by the philosopher Kant, who held that the mind arranged and classified everything by means of what he called categories, such as space, time, quantity, quality, with the result that we never know anything at all as it really is, but only in the form in which the mind has worked it up and arranged it for us. We are here at the starting-point of the philosophy of Idealism, which maintains that mind is the only real thing in the universe. A modern form of Kant's view has been put forward by the philosopher

Vaihinger. For him it is the imagination which wreathes fictions around the data supplied from the outside world, with the result that there is no reason to suppose that anything we know possesses an objective counterpart in reality which even remotely resembles it. "Our sensations," he said, "produce within the psyche itself purely subjective processes to which, in the modern view, nothing in reality —picture it as we will—can correspond." Hence the explanation of what we experience is to be sought in the nature of thought itself, rather than in the outside world.

Theories of this kind give rise to many interesting speculations as to the reality of the external world, which belong rather to philosophy than to psychology, and cannot be pursued here. We have introduced them only because of the emphasis which they lay upon the complete interdependence of all mental processes. You cannot feel the heat of the fire on your hand without perceiving that there is something that warms you; you cannot perceive what the something is without judging it to be a fire; you cannot recognize the fire as a fire without synthesizing your sensations of it, interpreting them in the light of your memory of past experiences, and, for all we know to the contrary, working them up and distorting them out of all recognition by means of the mental apparatus which insists on taking charge of and transforming the raw material that comes to it. We never get any impression from the world raw, it is always cooked; and from these culinary operations of the mind there is no escape.

SUMMARY

In this chapter I have tried to present a picture of the mind not as a bundle of mental units known as faculties, but as a dynamic ever-changing force, the activity of which conforms to a number of fairly well-defined types of behaviour. According as one type or another is most prominent, we say that one or other of our so-called faculties, instinct or reason, as the case may be, is functioning. But in point of fact the whole mind is present in each of its activities, and all its so-called faculties are comprised in each.

This way of regarding the mind is now accepted in the main by most psychologists. One of the oldest traditions in psychology, to which almost all psychologists have subscribed, is to distinguish in

any given state of consciousness three aspects of the state known respectively as the cognitive, affective, and conative aspects (knowing, feeling and striving). Nearly every experience, it is agreed, presents these three irreducible aspects. It is first of all a knowing or a thinking about something; secondly, it is a feeling about the something, whether pleasantly or unpleasantly; and thirdly, it is a striving towards or away from the something.

In any given experience any one of these aspects may be more or less prominent, but each is always present to some extent, even if in extreme cases—e.g., in that of the mathematician doing a problem, one of the aspects in this case the affective, may be almost negligible. It follows—and this is the conclusion that we wish to emphasize—that there are no *purely* cognitive, affective, or conative experiences. The aspects we have distinguished in mind are like waves on the sea; they are continually changing their form, they merge one into another, and they have no separate existence either from one another or from the sea which owns them. Yet just as, however smooth the sea, there always are waves, however slight, which can be distinguished in though not separated from its movement, so in experience we can always distinguish aspects in which the mind as a whole is at any one moment expressed. If we steadfastly adhere to this attitude to mental processes and apply it constantly throughout our psychologizing, we shall avoid many of the mistakes which psychologists have made in the past.

CHAPTER FIVE

THE THEORY OF THE UNCONSCIOUS

IMPORTANCE OF THE THEORY

IT WOULD BE misleading to conclude this outline of modern psychology without giving some account of the theory of the unconscious, although we have space only for the briefest sketch. The theory of the unconscious is chiefly of importance for psychotherapy—that is to say, for the practical treatment of nervous diseases and psychological abnormalities, and belongs, therefore, rather to what is called psycho-analysis than to psychology proper. In so far indeed as those who approach psychology from the psycho-analytic standpoint have sought to present a complete picture of the working of the human mind, they have been largely unsuccessful. But although the theoretical basis of psycho-analysis is highly questionable, there can be no question of the success which has attended the methods adopted by psycho-analysts in treating nervous diseases. These methods have been largely based upon the assumption that the unconscious as conceived by Freud is not a convenient hypothesis, but a fact; and the psychologist is, therefore, obliged to take notice of a theory as to the origin and nature of mental processes which in practice has been so fruitful of results. The subject is also important for another reason. If *all* that the most extreme supporters of Freud assert about the unconscious is true, then none of our conscious mental processes are free; they are conditioned in every case by unconscious elements whose genesis escapes detection, and whose workings evade control. This conclusion, if true, is of the first importance for psychology proper.

I propose, therefore, in the brief space at my disposal, to try to present in outline the picture of our psychological interior, with which the writings of the late Dr. Sigmund Freud, the Viennese psychologist, have made us familiar, and to give one or two illustrations of the life of its inmates. Before doing so, however, I should like to point out:—

1. That the theories of Freud are not accepted either by all psychologists or by all psycho-analysts. Another important psycho-analyst,

Dr. Jung, of Zurich, while accepting in principle the Freudian theory of the unconscious, arrived at very different conclusions as to its nature and the influence it exerts on consciousness.

2. That the whole theory of the unconscious is as yet pure hypothesis, and that not only do many psychologists refuse to accept it, but there is no sort of agreement among psycho-analysts themselves as to many of its salient features.

3. That, nevertheless, there can be no doubt of the important influence which the theory of the unconscious has exercised upon modern psychology. For this influence Freud is more than any other thinker responsible. His first book was published as long ago as 1892, his last in 1939, and he may justly be regarded as the founder and chief exponent of psycho-analysis. It is for this reason that I have chosen his conception to form the basis of the following sketch.

THE FREUDIAN INTERIOR

The individual's mental interior may be likened on Freud's view to a house with two floors, one of which is a basement. Each floor is inhabited by a different family. The ground floor family (the conscious) is small, select and respectable. It is conventional in the English way—that is to say, it is anxious to keep itself to itself, while at the same time determined to put up a good show before the neighbours. In this laudable endeavour it is continually embarrassed by the activities of the basement (the unconscious), which persists in the attempt to elevate itself in society by mixing with the family on the floor above. It is a large, primitive, untidy, disreputable sort of family, this basement lot, noisy and selfish, caring not a fig for respectability, and a prey to unbridled desires which it insists on satisfying without regard to the feelings of others. Apart from its laudable endeavour to raise itself in the social scale by penetrating upstairs and its volcanic energy, there is nothing good to be said for it. So at least the ground floor thinks, and, accordingly, with a view to keeping these unpleasant neighbours down, its inmates have hired a sort of policeman (called by Freud the censor), placed him on the staircase between the two floors, and charged him with the job of preventing the basement people from getting access to their own floor. It is upon this job that the policeman is permanently engaged, with the result that there is a

perpetual series of conflicts on the stairs.

These conflicts may issue in one of three ways:—

1. The policeman may succeed in keeping a basement inmate permanently and effectively under. Thus, denied access to light and air and deprived of his natural outlet, this thwarted individual (unsatisfied desire) may go bad and fester; like a stream that is dammed up and overflows into a stagnant marsh (complex), he may come, in time, to poison the whole of the house, affecting, however slightly, the activity of each one of its inmates (neurosis).

2. The basement inmate may win through in spite of the policeman, but only on conditions—namely, that he consents to be furbished up and made respectable. The violence of his primitive individuality must, in other words, be toned down somewhat to accord with the conventions of social usage. This process of being made fit for decent society (sublimation) may alter the primitive basementer out of all recognition. (Thus an unconscious desire to elope with your housemaid *may* be sublimated into a sudden aversion from pickled walnuts.)

3. The basement inmate may come through unaltered. This happens when the policeman is off his guard, especially when he goes to sleep. Hence in dreams we are frequently brought face to face with the inhabitants of our basements, and although, when we try to remember our dreams on waking, the policeman returns to his duties again and distorts the dreams in the process of recollection, dream interpretation is regarded by psycho-analysts as one of the best methods of disclosing the hidden secrets of our unconscious selves.

Many psycho-analysts hold that all the inhabitants of our ground floors are sublimated versions of the inmates of our basement selves, and members of the Freudian school assert that all or almost all our basement desires are sexual in character, although it should be added that the word "sex" is used by them in a sense so wide as to be to all intents and purposes technical.

Our mental life, then, may be likened to an iceberg; the part of it that appears to view is only a very small proportion of the whole; what is more, it is not the part that really matters. We used to think that we could to some extent control our thoughts and desires, and that we could, therefore, to a large extent be held accountable for what we did. The plain man in particular has been taught and is

accustomed to believe that there is in his soul an element or faculty called the conscience. The conscience acts rather like a barmaid in a public-house: the barmaid would permit the indulgence of a desire for a certain time and up to a certain point, and then "Time's up, gentlemen," she would say, " out you go," and out the desire would go, whether we liked it or not. If, however, the Freudian view is correct, conscience itself is a sublimation of an unconscious desire, and we are no more responsible either for its appearance in consciousness or for the strength which it exhibits, than for the appearance and strength of the other desires it seeks to control. In this respect Freud's theory issues in conclusions not dissimilar from those of Professor McDougall's theory of instinct which we considered in the last chapter, and like that theory, has the effect of seriously undermining the basis of moral responsibility.

REMARKS ON THE UNCONSCIOUS

I have no space for a more detailed examination of the theories of Freud and other psycho-analysts; nor is this the place for a criticism of them. It will, however, be sufficiently obvious, from what has been said with regard to the so-called "faculty" psychology in the last chapter, that the endeavour to conceive of the human "interior" in the somewhat picturesque terms that psycho-analysts adopt is bound to be misleading. We have argued against the assumption that the mind contains separate faculties, such as instinct and reason, and the same consideration must apply to consciousness and the unconscious conceived as distinct and persistent states.

The notion, for example, of an unconscious as a kind of underground dungeon in which repressed desires remain imprisoned, awaiting a means of escape, is far too dramatic to be accepted even as a symbolic representation of what occurs. When we temporarily suppress or forget a desire which subsequently recurs, we have no more ground for supposing that it has somehow somewhere persisted all the time than, to use a simile of Mr. Ogden's, we have for regarding " the return of spring each year as a proof that she has been lurking underground all the winter."

What persists is probably a certain pattern of the nervous centres, of the type which we described in Chapter Two. When the need which

prompted the original wish recurs, it finds this pattern awaiting it, and accordingly appears in our consciousness as a completely formed wish, carrying with it the feeling that we have experienced it before. It is on lines similar to those laid down in Chapter Two that many phenomena, which psycho-analysts invent highly dubious entities and faculties to explain, may be more correctly interpreted.

But though the theory of the unconscious upon which most psycho-analysts work may be somewhat crude and over simple, there is no denying the effectiveness of the cures which have resulted from an application of psycho-analytic methods. These methods have aimed at tapping the unconscious depths of the mind, and bringing their contents to the surface, and their validity rests, therefore, upon the assumption that the mind, like the spectrum, has certain invisible extensions, which are as important and as susceptible of investigation as its visible regions. The fact that these extensions must be conceived in terms of particular settings of the nervous centres rather than as pools or reservoirs of persisting desires does not affect the great value of Freud's work.

BOOK IV

THINKING

BY H. LEVY

CHAPTER ONE

ASPECTS OF THINKING

EVERY ONE THINKS. Not every one thinks clearly. Most people imagine they think clearly. Those who know they don't think clearly are thinking clearer than those who don't.

As you read these lines you are thinking. We need not consider now where exactly this thinking is taking place—in the head or more particularly in the brain, or whether it can be located at all exactly. All we need accept is that this thinking is being carried on by an organ inside your body. Also for the moment we do not consider the particular things with which the thinking is concerning itself, what we will call the *content* of the thought, although that is really a very important part of the whole process; just that you are a human being, the seat and agent of thought.

So when I look at you in these circumstances I realize that, as you think, some process is going on "out there." I can say that your thinking is an *objective* process, meaning thereby that it does not matter much whether I am looking at you or not, the thought process continues to go on in your head or in your body nevertheless. As far as I am concerned your thinking takes place objectively; that is my first conclusion about your thinking.

I am not the only person concerned about your thoughts; I am only the onlooker. You yourself are more intimately involved in it than any one else. You are the seat of the process, you are doing the thinking and *you are experiencing it.* You make contact with your thoughts internally, or as one says *subjectively*. You experience an aspect of *your* thinking that no one else gets. I can imagine what it is like, because I also do thinking, but as far as yours is concerned, you alone experience this internal, this subjective aspect of *your* thoughts. That is the particular or personal side of your activity; nevertheless it is one common to us all.

We say then that thinking has at once both a subjective and an objective aspect, or that the process called thinking exists *objectively* and is experienced by the thinker *subjectively*.

When you are thinking something special is happening to your

brain. It is undergoing some change. If I could see through your skull, I imagine I could watch these changes occurring. They are accompanied by tiny electric currents over your brain. Professor Adrian has actually devised a delicate electric instrument for following them as they occur during thinking. Once again we need not concern ourselves with the detailed nature of the movements that are taking place there. They do occur objectively. In that sense they are not different from the changes that take place, say, on the surface of stone, the kind of effect we call weathering. There is nevertheless a vital difference between the case of the stone and that of the brain; the difference between living and non-living material, between animate and inanimate matter. Although both show objective appearances of change, evidence seems to show that only animate or living matter experiences these changes subjectively. A human being is cut with a knife. A pencil is sharpened. In both cases the cut occurs and exists objectively; in the case of the living being only, is the cut experienced also subjectively. There is no meaning to the word subjective in the other case.

The first point we have to seize hold of, therefore, is that while thinking is a process that occurs objectively, that process is experienced, or felt, or sensed subjectively only by the thinker. It is something else that the onlooker gets out of your thoughts. We can perhaps appreciate this point in another and more striking way if we take an analogy to a certain form of thought, viz., memory, thinking of the past. Pick up a stone on a mountain side, and examine it closely. It is chipped in places, covered with scratches, some deeper than others. One side is more weathered or affected by air and moisture than another. If it were worth while you could piece together a great deal of the past history of that particular stone from a close study of these surface effects. Had the stone been a human being, every scratch and knock that left its effect on the surface would have corresponded to an experience that would have been subjectively or internally felt by the person. In varying degrees he would have remembered them. The scratches and weathering would represent the physical side of the stone's memory, if it had one. Once again note that the word memory is only used for those cases where there is also a subjective side; for remembering is thinking about past events. Thinking is always conducted in the present, but the centre of thought may be an image of

the past, a thing of the present, or a constructed image of the future.

How does an outsider become aware of the existence of the process going on inside the thinker? After all we do not see through people's skulls. Can thinking be conducted without any outward evidence showing itself? If indeed this were so how could we ever collectively get to know of its existence? We would have to imagine ourselves as immobile creatures with glassy stare, stiff lips, and paralysed limbs. We would not be human beings at all. For thinking does not show itself to us in molecular movements in the brain, but in speech sounds, movements of the lips, glances and twinkles of the eye, gestures of the head, hand and arm. It shows itself in behaviour. It shows itself in action and in the relations between successive actions we perform. We recognize a plan, a pattern in the activity, and we conclude that the individual has been doing something we do ourselves, thinking.

Take speech for instance. It is one of the outward, visible, and audible signs that thinking is taking place. The thinking may or may not be *good*, *accurate* or *clear*, but the fact remains that such muscular movements of the throat or lips are almost invariably a sign to us that thought of some kind is taking place.

There is ample evidence that this is so. Indeed, those who associate themselves with what is called the Behaviourist school of philosophy even assert that thought without speech in some form, however primitive, is an impossibility; that even when no sounds are emitted, what we call thinking is always accompanied by muscular movements of the throat. They go further than this. They say that since that is all you can see, since all else is unobservable, you have no right to suppose there is any other side to it. Thus to them thought *is* muscular contractions of the throat. The two are identical, they maintain. Now we have already perceived that thinking is both a subjective and an objective process. When an individual thinks, he may mutter to himself, pucker his brows, walk up and down. When he reads or writes "with concentration" we say he is carrying through a task that involves "brain work," and these are also some of the signs we usually associate with thinking by human beings. They are to us aspects of the whole thinking process. The Behaviourist stops at this stage and asserts that these are really all we can mean by thinking. He asserts this because he insists on restricting himself only to the outward signs

visible to the onlooker. But after all, *seeing* is not the only way we perceive things and processes. We may smell them, hear them, and *feel* them. Can we smell, hear or feel another person thinking? Rigorously of course if we maintain the attitude of the *onlooker*, we will only *look* on, we will only see, but we are thereby unduly restricting our powers to deal with the situation. Blind people think and can tell from speech and gesture when others are thinking. In an indirect way we can enter into the thought processes, or appreciate the course of these thoughts, of someone else. That indirect way is through our own subjective view or feeling of our own thoughts. But the thoughts that we feel in this way, thoughts that I am calling our own are aroused in us by the particular sounds emitted by the other person. The motion of the lips, and the sound emitted convey to us an expression of the feelings and internal reflections of the thinker, by arousing in us what we must suppose is a similar train of thought. What this really amounts to is that we assume or infer, that when another individual says something, the internal or subjective feelings he has are similar to those we have when we use the same words. In spite of any doubts that may arise concerning the justification for this inference, to the ordinary listener it is these speech signs and what they evoke, the mental images and pictures, the feelings of assent or dissent, that represent the most important element in thought sharing and thought passage. They produce a subjective reaction that to each of us is much more important than the muscular movements themselves, for the latter are to the speaker and to us simply the instrument for expressing his thoughts and evoking a response from us. This could be done by a gramophone. It is done by a book. It would appear therefore that the Behaviourist in refusing to recognize the existence of anything other than the instrument itself, the speech mechanism in this instance, is restricting himself simply to one very trivial aspect of the problem of thought communication.

Now there is a very important lesson in all this for us. To see this let us go back to our illustration of the stone, weatherbeaten and scratched, as we discovered it on the hill-side. What a marvellous description of its past history could be built up by a modern scientific Sherlock Holmes, equipped as he would be with profound geological knowledge, powerful microscopes for examining the surface scratches

and undulations, and the grains of foreign material that adhere to the surface; chemicals and balances for analysing the composition of these clinging particles; apparatus for hardness tests to discover the pressure and force of the blows and of the scraping it has undergone. By the time Sherlock Holmes had completed his investigations, smoked his many pipes as he pieced his evidence together, and pondered carefully his conclusions, you can depend on it he would have a fascinating tale to tell his friend Dr. Watson, a tale of wanderings, rollings and joltings to which the stone had been subjected over a long period of its past history, perhaps thousands of years. Endow your stone with a brain, not too good a brain—rather an inferior one—a stupid brain. Endow it with feelings and the power of language at a level to be expected of that brain and those feelings. That is to say, suppose it has words to describe its feelings, its thoughts. What could it not tell us of its wanderings, its hairbreadth escapes, the agonizing blows it was struck, the torture of the scratching and ripping it endured. Of the stone's own impression of its experiences, Sherlock Holmes could have told Dr. Watson but little. With his fertile imagination he could possibly have suspected but he could not have been certain of the whole story. He would require feelings and thoughts similar to those of the stone, to appreciate it properly. Can we ever imagine what a sparrow feels when caught in the claws of a cat? The higher the level we have attained in sensitiveness, the further are we removed from creatures less endowed in that respect, and the more difficult is it for us to descend emotionally to the lower level.

The picture can be reversed. How much of the history that the scientific detective had pieced together would the stone know? Excited and overwrought as it was during its struggles, what could it know of the dispassionate analysis of the geologist, the chemist, the physicist. The conclusion is obvious. The full story requires both the external and internal view. It has to be seen and it has to be felt, it has to be looked at objectively and it has to be experienced subjectively. Each presents us with only a partial picture. For let us remember that the more strenuous the experience the more positive would the stone be of the nature and explanation of its travels, and therefore the less competent to see the whole affair objectively, that is to say, as seen by the observer.

The converse is also true. The more objective one is, that is to say, the more one is a mere onlooker, the less competent is one to enter into the affair subjectively. It follows, therefore, that since events that affect human beings, and indeed also animals, have both a subjective and objective aspect, we will certainly be deluding ourselves if we imagine that either a purely objective or a purely subjective treatment is anything like adequate for the whole story. If we were to use the word truth to stand for "the whole story" then neither approach in itself can lead to truth.

There is, however, more in it even than this. How often have we heard the phrase "I feel intensely that this is true." No doubt. The statement in itself is evidence of the intensity of the feelings; but is it evidence of truth? Many people in the past have been convinced and passionately convinced, of the truth of falsehood. Many martyrs in history have gone to the stake in the false belief that they were dying for some eternal truth. The statement quoted reflects rather the subjective and internal aspect of something that takes place externally, but whether the reading of that event derived from internal evidence alone is consistent with the evidence that would be obtained externally is another matter. For this question of evidence, and this matter of "truth" are difficult affairs about which words must not be used lightly or conclusions arrived at without due regard to all the circumstances. We have to remember this when we meet people whose conviction of truth, and the vehemence with which it is expressed, is offered as evidence of the accuracy of what they assert. Certain "truths" may of course be mainly subjective, and objective evidence merely circumstantial. For example, if you tell me you feel a pain, how can I "verify" (note the word—verify=make true) your statement. You know whether or not you have a pain. You know by feel. It is a feeling. That is what the word pain is used for, to describe what you know you feel. If you are a schoolboy, and you tell me that you have a sore throat, and cannot therefore go to school, all I can do is to wait until you have managed safely to evade school, and as soon as I hear you singing or shouting loudly, pounce upon you triumphantly with the remark:—

"A boy who has a sore throat doesn't behave like that!" I check your statement against the evidence of other human beings in cases

where people say they have sore throats. Just as I had to deduce or infer the existence of your thoughts from your behaviour so also I have to infer the existence of your feelings from your behaviour. I check the theory suggested by your words that you have a pain, against your behaviour.

Many people "think" with their feelings. Here I am using the word *think* in a sense different from before. We have regarded thinking as a process associated with the brain, but we saw also that we, onlookers on other people's thinking, concluded from behaviour whether or not they were thinking. Now, thinking is not the only process that can be seen through behaviour. Feeling as much as thinking shows itself in action in this way.

"He is very emotional," we say, when we mean that in certain circumstances the individual is "carried away" or is "overcome." We suppose that his actions are being decided principally by his feelings, rather than by his thoughts.

"He is cold and calculating," we say, when his thinking guides his actions, and his feelings are smothered.

Now do not let us assume that "correct" action is necessarily to be decided either by thought or by feeling, either by being cold and calculating or by being emotional. Many a person has emotionally rushed to do the correct thing. Many a person has thought out his course of action carefully and done the wrong thing. Right action and wrong action (or shall we rather say correct or false action?) may have to be discriminated not by the process of arriving at the decision, whether by thought or feeling, but by whether "objectively" the action fits in with the process we intended to bring into being. All this we shall have to enter into in greater detail later on, but for the present we can see that correct or false thinking is not such a simple process as we may have imagined; that somehow or other it is frequently interlocked with correct or false feeling, and correct or false action. Furthermore, that since thinking has also a subjective aspect, it is probably in this respect that it links up with this question of feeling, that continually obtrudes itself in this discussion.

But first we must get ourselves straight on the use of words. Already in this chapter we have seen how easily we tend to use words loosely, and to confuse our thinking by that very looseness of expression.

CHAPTER TWO

THINKING ABOUT HUMAN SOCIETY

IMAGINE HUMAN HISTORY as a pageant set out along a strip of film about fifty feet long and unrolling itself from a dim, uncertain past, through the dark night of the Middle Ages to the definite outlines of the present. Here it vanishes abruptly. At one end our ancestral parent, scarcely distinguishable from the modern ape, gropes with blurred mind through a world he cannot realize, life a perpetual physical struggle, food above all his first consideration. At the other is the alert member of a modern civilized community, in masterful control of the forces of Nature, carried about hither and thither with incredible speed, within a few minutes in direct communication by wireless or telephone or telegraph with any other individual on the planet; the inheritor of a highly complex society with elaborate amusements, literature, music, science, intricate machinery for the provision of food, shelter, clothing and the satisfaction of his cultural interests. How has this transformation taken place? Let us examine this film in detail, a full hour to allow this fifty feet to unroll before our eyes, a motion picture, displayed with an incredible slowness which is nevertheless essential if we are to study it. Forty-nine feet of film creep steadily past our eyes. A bare minute now remains of the hour, and yet we have scarcely seen man pass beyond his early savage stage. Why has he moved so slowly throughout the ages? At last the beginnings of civilization appear. Fifteen seconds from the end while but three inches of the fifty feet remain, the Christian era begins. As the film creeps slowly on, and the last few seconds beat out, events begin to flash past with gathering speed. Two vital seconds are absorbed in the darkness of the Middle Ages, a cruel civilization steeped in mysticism and magic. An eighth of an inch from the end with yet one second to go, "Puffing Billy" flashes momentarily into view, and modern transport has emerged; the Industrial era has begun. With the last half-second there is a sudden illumination by electric power and the modern world flashes in; within the last thirtieth of an inch, aviation and wireless. Visually we can discriminate no more; slow, tediously slow as the film has moved, the speed of change dur-

ing the last quarter of a century is yet too fast for the eye to discern even the broad phases of what has happened. It finishes in a momentary blur. We pick up the film at our leisure and examine the end. To what heights, we wonder, must these human beings have risen, who in such an incredibly short span have shot up god-like in their mastery over time and space? The film tells us. At a distance equal to the thickness of a fine line from the end the climax from savagery to culture is reached; civilized man steeps himself in an orgy of blood and slaughter on a world scale, bringing to bear the highest refinements of brutality and the greatest powers of destruction with which he has succeeded in providing himself.

Such in brief is the history of civilized man.

What of his future? Dare we predict even a hair's breadth beyond the end of the film?

Why this slow flickering of a flame throughout the ages, why this sudden rise to brilliance? What has driven it on? How has it all happened?

If we are to discover how we do think, this is the picture we shall have to keep continually before our minds. We must know who we are, where we came from, and what has happened to us. We shall have to see ourselves objectively, as people that fit somewhere into this picture; subjectively as individuals with feelings and desires somehow associated with what has happened to us throughout all these long ages, members of that long procession that stretches throughout the 500,000 years from early primitive man to the present day. We shall have to discover what we have inherited from that vast lineage. For do not let us imagine that we can ever free ourselves completely from the shackles of the past. Scarcely more than 10,000 generations separate us from that grinning parent of ours who lived on what he could capture from the wild, tearing it limb from limb as he devoured it alive.

We are closer to the savage than we may imagine. It is unlikely that the little upstart, modern man, emerging so recently from an atmosphere of hate, and fear, and suspicion, can have done much more than press below the surface many of the habits and moods that governed the lives of his forefathers for ninety-eight per cent of their wanderings on earth as men. Our problem is to see this question of

thinking in its true perspective. We may go hopelessly astray unless that perspective be historical and social in the first place. For men have always been fragments of society, coloured and conditioned by the environment they thrived in; and this film, if it does nothing more, brings out to us how much of that environment was primitive and wild, how much of it was imposed by the combat with nature.

Now the first point to recognize is that in the case of no other animal could such an historical picture be produced. Animals certainly have evolved and some have changed in shape and appearance considerably throughout recorded time. Horses of Eocene times, for instance, were of the size of dogs, running on five toes instead of a hoof. What we have seen here, however, has not so much been the changes that have shown themselves in the physical make-up or the outward appearance of man, as in the society he has created. If one of our ancestors, say 50,000 years ago, were washed and shaved and dressed in evening clothes, I have no doubt that, apart from his social behaviour, he would nowadays pass unnoticed at any banquet. Or we can put it in another way. There are many human beings in present-day society who, in all but hair and social habits, and sometimes even in that, might well be members of the society of primitive man.

The first crucial point of difference between man and other animals, therefore, would appear to lie in the fact that he has a highly organized social life. How has it come about, then, we may ask, that man has succeeded where other animals have failed? Have they indeed failed? After all, he is not the only animal that lives in herds, nor is he the only live thing that lives in a complex society. Ants and bees live in communities and have a highly involved code of behaviour; could not a similar picture be drawn for them?

And here a word about the very language we have used in raising this issue. Why do we say that man has *succeeded* in building up a developing society, and ants and bees have *failed*? In doing so we seem to be implying a deliberate and conscious effort on the part of both. There was certainly no such consciousness. As we shall see in a moment, in the case of man success depended principally on the possession on the part of man of certain physical characteristics that no other animal or insect possessed to anything like the same degree.

Each generation of human beings begins life with relatively few inherited instincts, and what few there are are rapidly altered or transformed as the child undergoes its training from its earliest days. His physical appearance and his bodily structure he inherits from his parents, in exactly the same way and according to the same laws as with any other animal. His capacity for learning is, however, associated with his brain, and it is the brain of man that is unique among his brothers of the animal world. This must not be understood as an assertion that "intelligence" is, in individual cases, derived from the parents. What is to be understood by such a characteristic, and how it is to be measured in order to study its mode of inheritance, is a difficult problem and by no means yet solved. Rather is it man's capacity to learn and the physical characteristics of the brain known to be associated with this, viz., his large forebrain that remains a constant inheritance within the human family. When we talk of inheritance in man, therefore, let us recollect that there are in reality two processes going on at the same time. Individuals inherit physical features from their parental stock, and with this the study of genetics is concerned. But over and above all this, every new-born child inherits, from all previous generations, a vast storehouse of knowledge and experience, a code of behaviour, habits, and customs. As a human being he possesses a forebrain that is so plastic, so sensitive to change, that during the short span of his life he can acquire a fund of knowledge and experience that is approximately the summation of all that has been acquired by past generations of his forefathers. Every child in this sense stands on the shoulders of his parents, his grandparents, and, indeed, on the shoulders of all previous generations. His brain being such that he also can learn by new experience, he in his turn makes his contribution to the common stock and leaves the world richer for his having been born.

It is, then, this power to learn by experience and to pass this experience as social capital into the common fund that is crucial for man's evolutionary development.

His power over nature has thus grown by leaps and bounds. For every child enters into a world, changed by the discoveries and applications, small and scarcely perceptible as they may be, introduced by all his forbears. Each child benefits from these to a greater or less

degree and introduces further changes. Such a life, such a social environment, can never be static. Change and development is of its essence. In the individual, crude primary instincts and habits and routine may be of little consequence or of little direct value contrasted with the power to learn rapidly how to use, and how to benefit from, every change that he and his fellow members of society can initiate.

It is highly probable that for many thousands of years ants and bees have not changed the routine of their corporate life. They have built their ant-heaps and their bee-hives to an unchanging pattern. During this period man has transformed his savage state to that of modern communities. During the past three generations, for example, Western Europe, in becoming industrialized, has made the whole complex of habits and customs of the population undergo profound changes. It has passed rapidly from the agricultural and the simple handicraft stage to that of a population of dwellers in huge cities and slums. It has given birth to new interests and desires, and it has discovered new methods of satisfying them. In three generations the whole balance of its social life has altered in a profound and revolutionary manner. Compare this with insect life. What changes in social organization take place in three generations of ants or bees? Less than 500 generations ago our ancestors were wandering savages. What alterations in ant life takes place in 500 generations?

In nerve and brain structure man is anatomically a totally different type of being. His speech and his writings and his educational system have made learning possible with such a speed and on such a scale and to such a depth that as discovery follows learning and learning follows discovery his social life rises in leaps from one level to another; it cannot stand still. Growth and development are now an unavoidable part of its composition.

Do not let us imagine that because of our achievement in thus building up a complicated modern society we can pride ourselves on having done so deliberately and consciously. On the contrary, we have bungled and blundered, we have fought ourselves blindly into it. In succession we have tried and erred, succeeded and failed. Nor are the instruments we have forged for social life, the instruments of speech and thought, of construction and organization, in any sense

perfect. These also we have produced in a blundering and bungling way. We have muddled through to our present position. As new discoveries have been made, and new ideas have passed from them into the social texture of life, new words have had to be invented or old words have been strained in meaning to fit the new situation. With a gathering experience, thoughts and values change, the innumerable details of life take on new interpretations, new feelings and emotions are aroused. Language changes in their wake in the effort to express these things. Thoughts, feelings, actions, language, and social background generally, act and interact on each other, sometimes in step, but more generally out of step—a team of horses pulling and tugging, but with a pull in the same general direction.

Speech, in the sense in which we know it, is principally for the communication of ideas, the arousing of feelings in others, or for the issue of direct or indirect instructions urging them to action. The existence of a language of sounds therefore shows up one of the most significant differences between man and his lower relatives. It is a sort of word machine, to hand on experience from one to the other. I am no longer restricted to my own short life for learning what the world has to teach me directly. To some extent I can also live the lives of all those others with whom my common language enables me to exchange thoughts and feeling, and to compare actions. My opportunities for learning are multiplied by the number of people with whom I can converse.

But this is only the most elementary step. Man has gone very much farther. By the invention of the printed and written word, a symbol or sign for the sound, he can transmit a sound, as a mark, to a time and place it would not otherwise reach; he has thereby established a method of bringing the cream of the experience of previous generations, and of the creations of outstanding men of genius of the past, to a focus, for all to study who have leisure to read. In our libraries and museums, and in our spoken traditions, we have practically all that has survived of the past history of the race, available for our present enjoyment and edification. Language, written and spoken, has created a snowball of learning and understanding that grows steadily from generation to generation.

In this way it contains within it the possibility of deliverance from

the confusion of fact with fancy, that arises inevitably in the imagination of the individual, who must perforce lead a life restricted in time and place. When we look back on some of the isolated communities of earlier days we see how their interpretations of life were falsified by their limited experience. Devils inhabited stones, and gods dwelt on mountains; thunder was the wrath of angered spirits, and streams possessed magical healing power. Witch doctors wielded power in virtue of the ignorance of their fellows; the threat of danger from the unknown had to be deflected, and the spirits appeased. Signs and gestures, magic words and phrases, the subtle influence of the stars, all played their part in the explanation of the unknown. An isolated community was little more than a group of savages crowding nervously around a tiny spotlight of understanding, dimly illuminating the small circle of the known and accessible universe. Outside this lay the fearful, the mysterious, the magic.

In such a situation language developed. Explanation described the known in terms of the unknown, the actual in terms of the fanciful; and such a language have we inherited. Traces of it still remain in many of our simple, common words. *Lunatic* literally means moonstruck, an individual who has come under the influence of the moon. Here the abnormal behaviour of the individual is "explained" as due to a mysterious heavenly agency. We may long ago have given up this particular fancy, but how many more are there of this nature that we tacitly accept without question?

"We will beat it out of him," says the teacher or the parent to the unruly child. "He has a devil in him."

In our quieter and "saner" moods of course we laugh such beliefs and such actions to scorn, but are we always sane in this respect? Are children never beaten?

If a child has acquired a habit of which we disapprove, do we ask ourselves the scientific question:—

"What kind of an environment is required in order to modify the life of this child?" or do we say:—

"He is bad. He has to be beaten."

Is this not frequently but the ancient attempt to drive out a devil, sin, by physical force, a habit society has not yet given up either in public or in private? We may call it discipline, we may call it morals

or ethics, we may give it any grandiloquent name we care, but the fact remains that it may be merely the continuation into modern times of an ancient barbarous custom that has its roots in the fear of devils that may possess us. What is the modern attitude of many people to the doctor but that of ancient times to the medicine man and to the witch doctor? How many people still believe in the "evil eye," and use the expression habitually in their language? Have we eliminated the word *luck* from the language! Indeed, we can meet people every day who believe in charms. Have you a lucky number? Do you object to being married on a Friday? Do you throw spilt salt over your left shoulder, perhaps with a laugh, but nevertheless with a sneaking feeling that "there may be something in it"? How many people are afraid of the dark? Afraid of what? Unknown spirits? Ghosts? You are alone at night and hear a mysterious tapping. It is uncanny. What are these words "mysterious" and "uncanny"? Why are you nervous? I tell you there must be a perfectly plain and straightforward explanation in terms of natural and understood events. Yet you are nervous. How is it that your conduct does not seem to fit in with your reason?

We are a medley of fears and terrors lying just below the surface. Separate us from the crowd, separate us from society our parent, and we are at the mercy of every sound and shadow. We are thrown almost at once back into the primitive stage.

Have you ever watched a calf or a lamb from birth, how it persists in behaving as if it were still unseparated from its mother? Drastic action has to be taken to change the habit. They are put in different fields, inaccessible to each other. In the same way, when animals crowd together we call it the herd instinct. When a mass of people behave in a characteristic way we talk of mass psychology, as if it were something special and strange. Surely the picture of evolving man—evolving group men would be more accurate—suggests that we humans have first a social mind, and only nervously do we venture off on little mental excursions of our own, straying not too far from the common herd. That is what we mean when we say: "I mustn't think any more about this, or I will lose my sanity." It implies a fear of differing too much from the rest of one's fellow men. Sanity is surely simply "sociality," to coin a new word.

We can see this in yet another way. Try to picture all the horrors of the last war, the detailed stories of death and blood and slaughter, of drowning and stabbing, of burning with flame projectors, of the blowing up of fathers and sons with high explosive, of men choking to death with gas, wallowing for days and nights in mud, of whole shiploads of seamen drowning *en masse*, of men simply vanishing from one's side blown to pieces by shells. Try to imagine that you alone, in all the world, knew of this, and that you had to bear alone the knowledge of all this, for four and a half years—not knowing all the time when it was going to end.

Could you have kept your sanity? Yet millions did. If four or five sons of a mother in succession had lost their lives by a sequence of accidents in peace time, would it have been possible for the mother to keep her sanity? How was it possible, then, for women to stand up to such blows during that period and come out of it scarred and seared indeed, but still sane? Think of the fuss Job made over his troubles. Was all this not possible simply and solely because it was happening, not alone to the single isolated individual, but to the group, and as long as the group shared your experiences, so long was it possible to feel sane? When we talk of having faith in ourselves do we not mean that others also have faith in us? When we talk of having an individual experience, do we not also mean that others also have experiences like this and that we are sharing in something common? When we talk of thinking and reasoning, do we not mean a mode of thought common to our fellow members of the group? Even the most eccentric of us must find someone who will regard us as normal.

In our moments of speculation we are all prone to a certain conceit. We tend to regard ourselves as separate and distinct individuals *electing* to live together with our fellow men. Society then appears to be simply the mechanical combination of a large number of separate beings, each with his own individuality, with his own "rights," his own personal "freedoms," but willing for the sake of certain advantages that come to each of us from society to accept certain limitations on these rights and freedoms. As individuals we tend to elevate ourselves above the group and imagine we enter into a sort of contract with others, and with the organization these individuals set up

to regulate our relations one with the other.

We are now beginning to realize that this is a false picture, a false perspective. Society pre-existed us individually. We are born into it, we are a small growing point of it. We eat its food, imbibe its education, follow its customs and think its thoughts. It was there before we were born, and it will outlive us. Even our generation is only a passing aspect, a transient reflection of it. Although it is true that we are born with relatively few instincts, whether we are born with them or acquire them later, we have nevertheless locked up in us, hidden just below the surface, a mass of social affinities of the type that force us unconsciously to cling to the parent group. Within each of us there co-exists two struggling characteristics—one tying us to the herd, the other driving us from it.

Finally, do not let us confuse society with the State. The State is a particular form of government or organization of a section of society that has come into existence during a particular period of history. There have been times when social groups have broken away from State organization, as in the case of the pilgrim fathers. There have been occasions when the State has been upset, and a different form of group organization has been established. The Cromwellian revolution was a case in point; and during the past twenty-five years Europe has become a museum of such specimens. State organization adapts itself slowly, or changes catastrophically when it is no longer able to cope with the growing and changing needs of social life. That it is these growing hungers, changing and expanding from generation to generation that are the driving forces that take society from one level to another, is easily seen.

Compare the life of an ordinary workman today with that, say, of King Alfred. The latter in a position to command all that his society could offer in his day, yet had no gas, no electric light, no trains or buses, no newspapers, and no houses even approximating to modern workmen's flats. This does not imply that a workman today is likely to be any more satisfied than one of the days of Alfred. Satisfaction or dissatisfaction is the result of a conflict between what an individual receives, and what he feels are his needs. What he feels are his needs, rightly or wrongly, are closely concerned with what he conceives society can produce or could offer

him. It is the potential capacity of society to arouse wants and its actual capacity to cater for them that settles whether he will be content with his lot.

Society by its very nature keeps up a perpetual drive in the direction of arousing new wants. The repository of new knowledge and new modes of control over nature, accumulating from generation to generation, turning these discoveries always to application, society perpetually shows to its members ever new modes of living and experiencing, and therefore continually leads the desires of its members along unexplored avenues of living. It is when the State, the temporary machinery of organization, is no longer able to satisfy these needs that insurgence arises, the State is overthrown, and new machinery replaces it. Social life persists. States come and go. The imaginary film with which we commenced this chapter is a picture of the continuity of social life. Examined in detail it will be seen to show a succession of types of State at each level of society, ranging from early tribal forms, through theocracies, aristocracies, Medieval Papal States to Nationalist, Imperialist States and Socialist Republics.

CHAPTER THREE

THINKING ABOUT SPEECH

SOME WIT HAS remarked that speech was invented to hide thought. The attraction in the statement rests on the fact that it conveys a partial truth; but a truth not usually admitted. It has this additional interest, that it involves a contradiction. It is itself an illustration of speech being used to express thought.

Speech is, of course, not an invention, although artificial languages like Esperanto or Ido are. It is no more an invention than the gestures we make with the hands, and the grimaces we make with the face in order to express our thoughts and our feelings and to communicate them to others. It is a method of using the muscles of the throat and the larynx, rather than those of the arms and the face. That it has evolved in such detail that the lips, tongue and shape of the mouth also enter in elaborately is merely evidence of the fact that speech has been found to be an invaluable instrument for expressing certain special needs of man. As these have grown, the instrument has been elaborated and developed side by side with them. In discussing speech by itself, therefore, we must beware of the danger of separating it off as a process by itself, as if it had been specially designed to fulfil a finished purpose. The purposes to which speech can be put have been discovered by man with the growth in his power of speech. Its power has been made to extend as man's purpose has itself widened. Each whets the appetite of the other.

The function of speech then can be set out simply. It has to communicate a train of thought from one person to another. It has to arouse a sequence of feeling and emotion in the listener. It has to describe a situation; that is, it has to call up a series of mental images. It has to instruct individuals in a course of action.

To make any one instrument fulfil these diverse demands is no small matter, and the fact that human beings find themselves capable of using language for these varied and difficult purposes without conscious effort is itself evidence of the naturalness of the process for man. As we speak we are not very conscious of the exact words we use. That some kind of selective action is in being becomes clear

when we hesitate, when we find ourselves picking and choosing our words in order, as we say, to convey the exact meaning we intend. In general, however, as the words flow from our lips they reflect our thoughts and our feelings so closely that it is difficult to say whether we think before we speak, or speak before we think. Most public speakers have had the experience, sometime, of suddenly watching or hearing themselves speak, as if their words had a momentum or flow of their own, and their thoughts were being dragged along in their train. Words have indeed a momentum of their own, as thoughts have. Just as the process of writing by hand is too slow for some people, whose thoughts come out tumbling one over the other, and writing becomes irksome, a drag on thought, so indeed speech may on occasion be ill adapted to its purpose. Any one who has attempted to explain a complicated issue in a tongue with which he is not too familiar will know exactly where the difficulty lies.

"Do you really mean what you say?" someone asks.

"It's very difficult to explain," you reply. "It's very difficult to find words to express exactly what I have in mind."

There in a nutshell is the crucial difficulty in language, the problem of finding the exact words to fit to objects, images and processes, whether they be of a physical, emotional, or mental nature.

It is sometimes remarked by educationists that any one who cannot explain his meaning does not himself understand what he has to say. This is a hard saying, for it implies that understanding can come only with the translation of the thought into speech symbols. But it involves more than this. It implies that language is a perfect instrument for thought expression, that its growth constantly keeps pace with the gathering experience of the race, an assertion that it would be difficult to support. Have we not already seen that embedded in any language are innumerable fallacies and assumptions of the past, so hidden in its phraseology that we are frequently satisfied with explanations that are indeed little more than word-spinning.

For explanation is what lies at the root of all thinking. It lies at the basis of all science, and as we shall see later it is also implicit in art. Man is an explaining animal. If he is not doing it to someone else he is doing it to himself. It is explanation in one form or another that connects up man with the whole of his environment, the struggle to

resolve puzzles and contradictions. To suppose for a moment that explanations must always be couched in words is to imagine that life is simply one colossal speech. True, if we are concerned to clear up (as we say) an idea, we frequently use words and their power of calling up mental images for this purpose. In one way everyone who writes a book does so. But equally you may have the *how* and the *why* of a certain event or a certain remark made clear by appreciating the feelings of the individuals concerned. To communicate these explanatory feelings I may either gesticulate if I am angry or excited, or I may sob if I am overcome, or I may laugh if I am hilarious. Even if I do explain in words, it may not be the thought, but the feelings concerned that are the crucial factor in the explanation. This I may do, for example, either through the tone of my voice—for instance I may shout—or I may emphasize certain words.

Take, for example, the question:—

"Why did you do this?" and roar it at the top of your voice. Now repeat it softly and tenderly in an appealing whisper. Then take the same set of words and, repeating it five times, emphasize each word in succession with a roar and then tenderly. These are only a few of the ways in which the same set of five words may be handled to convey a whole variety of feelings and emotions and to direct the attention to various facets of the same issue. To suppose that the words alone tell the whole story irrespective of their emotional context is to disarm ourselves of one of the most powerful weapons mankind has forged for purposes of explanation.

You may find yourself saying, for example, after a period of puzzlement:—

"I know why he did it. I know exactly how he felt. I would have done it myself." Or:—

"I see his reasons. I agree with him." Or:—

"Now that explains it. You see what he is doing."

Here then we see the possibility held out of explanations that are deemed satisfactory (note the word, for it expresses a feeling) being arrived at either by direct approach through the emotions, through the reason, or by action, through the visual sense. These matters we must appreciate if we are not to be tied hand and foot by words, if we are to become their master and not their servant.

We conclude then that in any attempt to convey thought by words, in all probability we cannot escape also arousing feeling and either stimulating to action or at any rate affecting future action. We could possibly go further than this. If we attempt to use words to arouse one of these alone we inevitably arouse also the other two in varying degree. Sometimes of course the others are scarcely noticeable. It is supposed to be the sign of a good soldier that he will obey a command without question (that is, without thought), and unflinchingly (that is, without feeling), and there is no doubt that the drill-sergeant's method has very frequently been highly successful. He is the past master in the science of the conditioned reflex. After a few weeks' military training "'Shun" invariably produces its desired reaction on the recruit, unaccompanied to any perceptible extent by either of the other two components.

And now we can pass to the next point. Normal language itself is not likely to be adequate for the conveying of certain precise ideas. It is for this reason that the chemist, the mathematician, the physicist, the biologist, the engineer, and the medical man, all find themselves compelled to devise special terms to represent the peculiar processes with which they have to deal. Scientific *jargon* arises from the inadequacy of ordinary language to provide precision in thought and action.

It must not be assumed, however, that it is only in the orthodox sciences that it is necessary to create a "jargon." All forms of precise thinking tend to suffer from the looseness of ordinary speech. Modern philosophical writers, e.g., those who call themselves logical positivists, have come to recognize the importance of devising a separate form of language in terms of which philosophical issues can be discussed, and properly phrased, without ambiguity. This is all to the good, but even so it has to be remembered that in the very process of defining their terms and setting up their new language, their explanations have to be couched in terms of the ordinary tongue. There is no escape from the natural language that human beings have evolved in their social life, but the logical positivists have made a distinct contribution in the fact that they have shown how that evolution can be pushed one stage further by conscious planning, as it were.

It is worth while at this stage mentioning a further contribution made from that school. They have given great thought to the problem of how precisely to formulate a question, and what type of question is sensible. In this respect they have drawn on the experience of science. We can illustrate it with a simple case: when we ask "Is the universe real?" it can be contended that this is a fictitious question because there is no method of giving meaning to the opposite, namely, the unreality of the universe. The logical positivists would maintain that much of the discussion that has centred in the past around the reality of the universe, or otherwise, has dealt with a false issue. While one cannot but agree to this argument, the implication that it was unimportant to discuss the issue is itself false. When such matters have been raised in the past this has occurred because historically it was on such a matter that the struggle between certain schools of thought was focused. If the broad issues that separated these schools were of importance in the development of thought, and of the theory of human action, then it was essential even to discuss what appears now to be fundamentally a question of a metaphysical nature—viz., one that could not be decided by physical means that did not thereby beg the question. Even today the matter is of importance. In the realm of mathematical science, in which tremendous strides have been made in the mathematical explanation of many natural phenomena, there are outstanding scientists who maintain that the thought processes of the mathematician suffice in themselves, without contact with any external reality, to answer all scientific questions that can be raised. To them, therefore, the universe is a pure thought, and in this confusion it is a short step to assert that this universe of thought exists only in the mind of a supreme being who is himself a pure mathematician. Because at this historical juncture such a type of confused thinking can be published, and accepted by large masses of people, who naturally talk in the common language and not in that of the logical positivists, it is essential to accept the issue of the physical reality, or otherwise, of the universe, as one that requires examination and answering.

The language of science is one of ideas and of practice. Feeling finds little place in it. A musical notation on the other hand is a

language for the issuing of instructions how to act towards a musical instrument, including the throat in singing, and for the arousing of certain feelings. It is only in a subsidiary sense a language of ideas. Many people who cannot sing or perform on a musical instrument enjoy reading music. Like poetry it is an "emotive" language to them. Scientific language is primarily "referential."

Once more we see how it follows from all this that any attempt we make to test whether a statement has "sunk home," to test whether the words have conveyed the meaning intended, is invariably by a study of the behaviour and actions of the person. Whichever way we turn in this matter, therefore, we appear to be confronted with the difficulty that never do we seem to encounter "pure thought" by itself but always in some degree in association with these other elements. That does not imply that we cannot follow the changes through which thought processes go, but rather that we will make a serious mistake if we assume they are a set of self-existent independent steps. Thoughts are processes that take place in the brains of sentient active people. They have to be seen in their human context.

What applies to thought in the human context applies equally as we have seen to the human being in the social context.

What applies to human beings in the social context, and to thought in the human context, applies also to language in the human and social context. If we ignore this we may find ourselves easily involved in argument with ourselves on foolish philosophical issues. Take the solipsist, for example, in his relation to language. He maintains that since all of which he is really aware are his sense data, he has no reason to assume the existence of any world outside that of his own mind. His senses and his feelings are the only reality. All else including you and me and the rest of the universe, past and present, are simply creations of his own imagination. This would not matter at all if he were content to behave as if this were so, but almost invariably he is a very argumentative fellow anxious to convince others that he is right. It is, of course, difficult to see what it will avail him to convince these others that they are, after all, only his sense data; but notice, please, that in attempting to argue his case he makes use of *language* and illustrations drawn from the common

speech, words that have a meaning only on the assumption that the words he is using refer to objects that exist both for him and the rest of society. His very phraseology denies the conclusions he seeks to establish. It is all a stupid confusion. Man cannot jump out of his own skin. He has grown up in a social environment where the existence of the objective world has been involved by the mere fact of the structure and growth of the language he uses, and by the practice he and his ancestors have carried through, in building up that social life and evolving that language. He ought not even to use such a simple word as *is*. A solipsist if he insists on remaining logical, and he always appeals to logic as his test of truth, without inquiring what is the test of the truth of his logic, must develop a language of his own—one he cannot share with those others who imagine they exist. It cannot be a social tongue. It cannot refer to objects as if they existed for us all, or as if they existed independently at all. It cannot appeal to the reason of his hearers since the hearers do not exist independently of him and they can have no independent reason to appeal to. He can only convince himself, and that he need not do. He is already convinced. He can argue only with himself, and he can adduce no evidence either rational or material. There could be no meaning to rationality other than what he himself held was rational. All this crazy philosophy arises not only from divorcing the individual in thought from the social background in which he plays a role, but, important for us, in divorcing language from its historical, social and material setting. These all involve each other. They could not be what they are without each other. Each has to be seen against the background of the other.

We can see the danger of a similar sort of false isolation when we come to examine the detailed structure of language especially in relation to the meaning it is intended to convey. We must not imagine, for example, that each word carries its unique interpretation about with it—one word, one meaning, as it were. A good dictionary will soon disillusion any one of that. Take, for example, the phrases: "Well, really, you're a beauty, to do a stupid thing like that." "I spent a beautiful evening last night." "The beauty of doing it this way is that," etc. "Truth, beauty and goodness, the three absolutes." "What a beautiful" sound, sight, smell, taste, sensation,

thought, proof, argument, trick, etc., etc. It becomes a platitude to say that the interpretation of a word depends on its context. Every expert politician knows that the way to cause discomfiture in his opponent is to drag his sentences about in this way. A new context suggests a new interpretation. Nor is the context necessarily a verbal one. Speech is uttered by human beings, and different individuals making the same sounds most certainly stimulate in their hearers different interpretations. When the Conservative leader of a modern State says: "We must all be Socialists now," we do not confuse his meaning with that conveyed to us when the same words are uttered to us by the leader of the Communist Party. We wait quietly for the qualifications, the rest of the context that makes the statement consistent with our view of him as a Conservative leader. There is, therefore, also a speaker's and a hearer's context. The same speaker, if he were unknown to his hearers, making this same statement to a meeting of Conservatives would certainly convey a different interpretation from that conveyed should his listeners be Communists. We commit a crime against clear thought if we drag words or sentences from any one of these settings.

Finally, words have a social class context. I am not referring to the fact that different strata of society are prone to use their own peculiar slang; that, in a sense, is an extension of language, although it brings out the fact that the spread of language is not uniform from class to class. Take, however, such words as: strike, hard-up, wages, salary, poverty, work, holiday, accident, culture, art, literature, science, machinery, sport. . . . All these words can with varying frequency be found in the language of all classes. Now just as the word football is differently interpreted and differently charged emotionally accordingly as the individual is a participant, an enthusiastic onlooker, or simply bored by it, so with such words as strike, hard-up, wages, poverty. The background of experience from which the meaning of these words is drawn, differs profoundly from one class to another. Think what the term: "A shilling increase" means to you personally, and compare its importance to members of another class, and the contrast becomes obvious. The varying emotional content of words common to all classes is one of the most delicate measuring rods for distinguishing class differences.

CHAPTER FOUR

THOUGHTS—THINGS—SIGNS

WE SAW IN the last chapter how necessary it is to remain aware of "context," both in the thinker himself and in the language he uses to communicate his thoughts. When these thoughts are concerned with the realities of the world we live in, the language in which they are expressed, then, must bear a direct relation to such realities, else we may find ourselves talking about fictions, ideas without objective reference. For reason changes to unreason when fact is confused with fantasy.

Let us examine this matter in detail. I hear the word *table* uttered. It is a sound, a sign, a symbol. A certain picture or image comes to my mind. I recognize it as a something that falls within my experience. There is an *idea* aroused with the sound, a certain thought process is evoked or stimulated in me by the use of the word. So far, then, there is the sign or symbol in the first place; secondly, there is the idea. How do I come to form the idea of a table? Clearly from my past experience of real tables. Personally, I always think of a kitchen table, but others may imagine something much more elaborate. Without the experience of a real table to provide the content for the imagination the idea could not be brought to a focus. There must be some real thing or some object or some process that is thought about. We do not form thoughts out of nothingness. We compose our thoughts out of realities. We are therefore led to recognize that in a situation of the type considered there are the three essential elements :—

(1) Word or symbol.

(2) Idea or thought.

(3) Object or objective process.

We have approached this trinity by supposing that the uttering of the word has aroused the idea. But the idea may have been aroused in some other way—it might be the sight of a table, the odour of cooking, and so on. However it is aroused, these three elements are necessarily involved in the resulting situation. That is

the bare bones of it all. Instead of having an object, suppose we have a quality of an object. Take the word *red*, for instance. It describes a quality of a poppy, of blood, of a ruby, of a sunset. It immediately calls up a certain picture or image, an idea, or a feeling, or an idea accompanied by a feeling. This image has been evoked in the past from such objects as I have mentioned. In all cases there did exist this objective reality, this something from a quality of which the idea is drawn and to which the word is attached. Again there is the word, the idea, and the actual quality of the actual object.

Now let us proceed a stage further. Take the word *redness*. An idea certainly corresponds to it . . . the idea "being red." It is a noun, not an adjective. Is there an object, a something that is "redness"? Clearly there is no such object, nor is it a process. There is simply the idea. Then how are we to complete our triad? What physical state of affairs, what stimulus, has aroused the idea? That is the question we are endeavouring to answer. Surely the same stimulus as aroused the idea in the adjective *red*—from red objects. It is simply a noun that says the same as before, a red quality exists, or red qualities exist, an invented word to represent a series of reds—the red quality of a series of objects. It is a fiction if it suggests a *redness* exists. Now, do not let us become confused. We are not asserting that the *idea* of redness does not exist. It does; but it is the idea in our head and not a "redness" outside. We could therefore form our triad from this, provided we have a word to stand for "the idea of redness," which is now the "object," we are considering. Call this mental process, say, by the name X. Then X is the symbol for an actual idea, viz., *the idea of redness*. As we discuss this we have thoughts about this idea. Thus we can now make our triad as follows :—

(1) Symbol X. (2) Thought about "idea of redness." (3) Idea of redness.

The point simply is that we can have *real thoughts about fictions*. The confusion we must avoid lies in assuming that because our thoughts are real, so also is the "object" of our thoughts.

When a fiction of this nature is analysed it is always found to be composed of parts that are drawn from reality. We can imagine angels, although we have never seen angels. We have, however,

seen real bodies and real wings. An angel, in the way in which it is conventionally pictured or sculptured, and if the word is not taken to refer simply to the sculptured piece, is therefore a fiction although its separate parts are drawn from real enough situations. Fiction is the correct word for this, for all good fiction draws its strength from real sources.

The triadic analysis has exposed some of the dangers that lurk in the word. Unless we had made this analysis we might have been tempted even further into error. It is an easy but false step from the word *redness*, for instance, and the idea associated with the word to refer to a principle of redness running throughout all red objects. Thus, in referring to it as a principle we tend to erect it into a special thing by itself, thereby granting to it a sort of independent status to which it is not entitled.

Language is pitted with traps of this sort. The danger consists in conceding to the idea associated with an abstract noun, some independent objective existence and erecting it into a principle. This can be seen even more acutely if we take such an adjective as *good*, in the moral sense. "So-and-so," we say, "is a good man," and any one of us may form for himself the triad: word, idea and object, to which *good* refers. For each of us the triad is complete. Two dangers now face us. You and I, in the first place, may not agree about the *meaning* of good. The difference in our meaning would show itself in our actions, for we may not agree about applying this adjective to the same object or individual. We test it in practice. We may value or judge the individual's behaviour differently. How that arises we shall have to examine later. For the moment it suffices to realize that we may all attach different values to the same element in a situation. Thus we see that the triad, even when it is completed, is not unique. It is not the same for us all. Nor does this finish the business.

In the second place we may fall into the same fallacy as before, and using the abstract noun goodness invent an independently existing entity, as if goodness existed "out there" as a principle in nature. Please note again that this in no way denies what is a fact, viz., that each of us has an idea "goodness." What it does do is to underline its dependence on each of us individually. For the word good from

which the notion is derived has itself a different status either from the word table or the word red, both of which are universally accepted descriptions of something objective, while good is a much more personal description of something objective.

Let us now turn to a more purely scientific illustration. The scientific conception of heat. As before, we begin with the adjective *hot.* Corresponding to this word there is an idea associated with the sensation. This we derive from objects that convey this sensation to us when we touch them. The triad is complete . . . word, idea and object. Now consider heat. Scientists find themselves talking of heat passing from one body to another. There is supposed to be a unit of heat called a calorie which is the amount of heat that will raise a cubic centimetre of water through one degree centigrade. This simply helps us to express one "quantity" of heat in terms of another, and does not get us any farther in our search for a precise *thing* called heat. What is this heat that "flows" from one body to another? What is this thing whose quantity or amount we think we can measure? The special term heat, and the use of such metaphors as "the flow of heat" convey to us the impression that it is something of the nature of a liquid which flows continuously through the interstices of the body, without increasing its weight but merely making it feel hotter. What is this subtle heat that weighs nothing, is invisible and is odourless, but whose presence is detected by a sensation that a body is hot? Admittedly the notion that it *flows* or is conducted through a body, and that there is a certain "amount" of heat present is a very useful one to science, but many fictions are useful to science. A scientific fiction is usually an analogy that assists the imagination so that the grouping of ideas may be more easily performed. It is a scientific convenience provided it is not overdone, otherwise it becomes a drag on thought. For many purposes, for instance a mirror adjacent to a lighted candle, may be replaced by a fictitious candle situated an equal distance behind the position of the mirror; but not for all purposes. Is heat such a fiction? Scientific textbooks will tell you that "heat is a mode of motion," or "heat arises from the agitation of the molecules of the substance," or "heat is a form of energy," all of which goes to show that in point of fact there is no such independent "thing" as heat, but that it is simply a

convenient form of expression to say that a body is passing through a certain process, its molecules have reached a certain pitch of agitational motion, and that when we put our hand on such a body the impact of the moving molecules against the hand produces in us the sensation of *hot*. Heat, therefore, refers to a process that is going on, a changing quality of the body, and does not have an independent existence, flowing here and there. That is a fiction encouraged by the separate term heat. Actually, of course, it is a very valuable idea, but the fact that it is valuable as an aid to the imagination does not grant it this independent status.

We can state our point in this way. Language may be "referential"; that is to say, the words may be used as symbols to point out some actual object or some actual process that is going on among objects. In using them in this way we may say that the words "refer" to the object or process. Sometimes, however, they are referential in a secondary way. They do in fact refer to an actual process, but their form suggests that they refer to some super-entity standing over and above that process. Heat actually refers to the process of agitation of the elementary parts of the body, but it is used as if it referred to some subtle fluid substance that made things hot. Very much the same point is involved in the use of such terms as justice and goodness. Where the difference lies is in the fact that heat is referential in the objectively scientific sense, in the sense that all people can accept and recognize the real state of affairs to which it refers, whereas justice is referential in the subjective or personal sense in that individuals may differ profoundly concerning what may or may not be called "just" actions.

Language is not however always referential only. The ideal of scientific language is to be only referential. If, however, I use the phrase: "Look at that dirty cad," not only is the term "dirty cad" referential, but it involves a personal judgment, stated in a form that arouses one's feelings. It is *emotive*. My purpose is, then, not only referential, for I am striving to arouse adverse feelings, dislike, the very factor that scientists strive to exclude from their investigations. In one sense the scientific ideal is definitely unattainable. Its language has to be understood. The reference has to be "taken" by human beings. It has not only to be perceived but valued among other

references, and therefore it has to be felt. Even the most "abstract" science has to carry conviction; and being convinced of a truth is not simply an intellectual process, it is also emotional. For its purpose, nevertheless, the scientific ideal in language is of fundamental importance.

In carrying through this triadic analysis we have been carrying through a process of thinking, but by putting the signs or word symbols alongside each other in this triangular way we have been making a more definite and precise picture of the relation of the component parts one to the other, so that we may see what they signify. We have been interpreting these signs to ourselves. Thinking involves using and interpreting signs. If I write or if I say "It is raining," what I write or say is interpreted by you in terms of certain climatic processes. This is quite evident in the example here given. We become so used to finding the interpretation to our words in the physical world in this way that we tend to accept all forms of expression as if this kind of interpretation were always possible.

In a sense the words develop momentum of their own, and we drag along in their train fooling ourselves that we are indeed thinking. We can check our phrases at any moment by demanding their interpretation. Now, there are very many fields of study where the objects of thought are not at first sight material objects or qualities of such objects or even ideas themselves. Words may themselves become the object of thought. If written, they exist as actual black marks on a sheet of paper. If spoken, they exist as sound waves.

In this way we may study the structure of sentences, i.e., grammar; or the history of words, i.e., philology; or the structure of languages, i.e., linguistics. Study involves interpretation, and in all these cases the interpretation is in terms of the something objectively existent, and can therefore legitimately be placed on our triangle. The field of interpretation must exist objectively.

We are now ready to raise a problem that may appear at first sight to contradict much that we have already asserted. Take the word *table* again. Are we really referring to a definite object? If so, which table? No special table, of course. I have already said that I almost invariably think of a kitchen table, but even then, as far as I am aware, it is not any special one. If so, am I entitled to say that the

reference is really to an existing object? There may not be a table in existence of the kind I have in mind. Let us try with another word, a scientific term again, an atom of hydrogen. The modern physicist or chemist will give you a very concise picture of the structure of an atom of hydrogen showing its electrical composition, and the detailed arrangements of these electric charges. In any triadic representation, which atom of hydrogen is being referred to? Any atom of hydrogen, you may say, it does not matter which. But are all atoms of hydrogen the same? If two atoms of hydrogen were placed side by side, would they be identical? Evidently we could not expect this. To begin with, they occupy different positions in space and they have been jostled about in different ways so that if their parts are in vibration or in motion in any way we might reasonably expect to find differences. After all, it is only a few years ago that we were under the impression that all atoms of chlorine were the same, but we have learnt now that there are various kinds of chlorine atom. We also know there are various kinds of hydrogen. When we use the words *hydrogen atom* to what are we referring? Do these words not refer to real objects at all? Of course they do. There are real objects called tables, and hydrogen is a real gas with real atoms. Then to what would the term hydrogen atom refer in our triangular analysis? Let us see.

Any particular object has a whole mass of qualities, its shape, its colour, its speed, its flexibility, its fluidity, or its rigidity, and so on. If we are not *interested* in any other quality but that object's colour, and if with a series of other objects we are also interested only in its colour and in each case for the *purpose in hand*, we find by trial that we do not require to go beyond the colour, we must say that, for the purpose in hand, the objects are identical if they all have colours that are indistinguishable by test. That is the answer to the whole question. When we say *table* we are talking about any particular one of a series that for the purposes in hand are indistinguishable. The same thing applies to hydrogen atom. For the purpose in hand we need not distinguish between one atom and another. All we need are the particular characteristics that enable us to group gases as "hydrogen" and "other gases."

In this discussion we have, however, introduced a new factor. We

have had to qualify our statements with the phrase "for the purpose in hand." Associated with this purpose arose a particular "interest," and that interest showed itself in selecting or isolating one quality out of the complex situation that faced us. We sought to fulfil this purpose by applying a process of selection. Note particularly that in introducing purpose and interest in this way we have begun to connect up our triangular analysis with the setting in which it is used in practice, i.e., with the active process of thinking.

Two other points must be seized on. In the first place we see that the group relationship symbol, idea, and object is not simply a self-contained stage, a static step in the analysis, but is connected with a process of movement of ideas or thinking, and we have ourselves merely separated it out because *we are interested in it for a purpose*, the purpose of recognizing a stage in thought-activity.

The second point is that, driven on by our interest and thus selecting one quality out of a situation and linking up a whole series of situations because they also contain this quality, we have formed a class. This is how the idea of classes is formed in practice. Every time we isolate a characteristic in an object we make that object a member of a class—the class of objects that have a characteristic indistinguishable from that isolated.

Let us review in a few sentences the ground we have just covered in order that we may see its meaning for us. We have seen the value of treating the terms we use to an examination by means of the triangle—word, thought, and object or process, if we are to keep our minds clear and our thoughts straight. We have examined the dangers that lurk in our path if too easily we accept the word alone. We have turned to the object or process and we have seen how closely linked the particular object is with the class or classes to which it may belong. The class is selected by us by an examination of the object and by concentrating our attention on one of its characteristics. Objects that have this characteristic thus compose a class. It is a man-made grouping, for it is related to the purpose involved in selecting just this characteristic for study. Any thing is thus a particular thing, and at the same time in some respects is typical of a class.

We will illustrate this matter in detail. My purpose is to explain

what is called the relation between the particular and the general. "For the purposes in hand" I am interested in the piece of paper on which I am writing.

It is an object in itself, a *particular* object just this piece of paper. It is white; it belongs to the class of white objects. It is flat; it belongs to the class of flat objects. Its edges are straight; it belongs to the class of straight-edged objects. We may carry this on as long as I can isolate any special characteristic. For each of these classes it is typical. This object is both a particular entity and can serve at the same time as a *sample*, by means of which I can discriminate whether any other object belongs to one or more of the classes I have mentioned. It unites particular and general in one.

If it is the case that we form classes in this way by generalizing from the particular, can the process be reversed? Can we use the general to particularize? That is precisely how we do particularize.

"What sort of a person do you mean?" I ask.

"He has red hair," you say, "freckles and a snub nose, rather undersized and knock-kneed." Here, red hair places him in one class, freckles in another, snub nose in another and undersized and knock-kneed in two more. In one sentence we have placed him in at least five categories or classes. There are others. For instance, he is not bald. By multiplying the classes to which the object can be seen to belong, we gradually particularize it; but such a form of particularization may never succeed in identifying it. We may simply succeed in finding a more and more restricted class to which it belongs. If at any stage, however, we are given *all* the members of a class, any one may be identified by an exhaustive enough method of cross-classification of the type we have considered. Where all the members of a class are not given, but the classes are formed by carrying the *samples* about from object to object, as it were, the method of classification can never succeed in fixing the object uniquely once and for all. Even if we were to try to do so by stating when and where it will be found, that is, its position in time and space, we have in the last resort to specify that place in terms of other objects that have likewise to be specified. Description is always relative in this sense.

We conclude from all this that the whole story about an object cannot be told in terms of its general properties. It has also to be

particularized by pointing out *the* object concerning which these general properties hold. In the same way merely to point it out tells us little. As soon as we want to know anything about it, as soon as we begin to study it in detail, we start sorting out the various classes into which it falls.

There is one way and one way only of convincing oneself that this is a just and accurate statement. Test it out in practice. Take any object near at hand and proceed to describe it. You will find that all your statements refer to the classes to which it belongs. And this is inevitable, because *every common noun is itself the name of a class*—table, man, fruit, orange, orange-peel, orange-peel colour, shade of orange-peel colour, etc., etc. By no possible detailed description do we ever get down to the particular orange we are talking about. The actual orange has finally to be produced—*this* orange—accompanied by a gesture. This is not at all surprising. We have pointed out already that in our triangular analysis all three elements must be present, and the actual orange, if we are interested in it, must have its place on the triangle. It is the object referred to. If we talk only in terms of classes we can, by making any combinations of them we care, invent fictions, and we would never be called upon to produce the actual thing. Angels were a case in point.

We began this chapter by stressing the need for becoming aware of context. This is precisely what we have been doing here. We have been trying to bring out the context in which an object has to be seen, that is, the various classes that cross it, meeting at the object; the society of other objects within which it occupies a place. Moreover, we have seen that it is only in relation to other processes and objects in the universe that its meaning for us can become clear. A pail may be described as belonging to all sorts of classes; but for one purpose, a social purpose, it is one of the class of objects that are used for carrying water. Thus at one and the same time the object has to be seen in its social context among other objects and among human beings. In this sense we have to regard it as interconnected with everything else, merely a fragment of a larger society, and it begins to have a meaning for us only when we take it as a sample, or as typical among these other things and compare it and use it for some purpose.

CHAPTER FIVE

METHOD IN THINKING

IN OUR DISCUSSION so far we have been isolating those elements that are related to the problem of clear thinking in order to examine how far they throw any light on the general process. This method of separating out the elements in a situation and studying their interconnexion is the first and indeed the principal step in all thinking. Our treatment of the subject thus serves to illustrate the subject itself.

A connected train of clear thought can be seen to have a very simple structure. It begins with the asking of a question, and it finishes with a partial answer. That answer is itself the starting-point for the next question to be asked, and therefore begins the next phase of the process. Accordingly, thinking has to be seen as a process that proceeds in stages, where each leads to a higher level of understanding than that of its predecessor. To achieve clarity in thought we have to become conscious of the presence of this process in our thinking; in so doing we acquire a surer grasp of what is required to guide our thinking to its objective. We become conscious of the necessities of the situation.

Now the crux of the matter is, of course, the asking and the answering of the question. How is the initial question to be asked and what plan is to be followed in seeking the answer? In stating our problem in this way we are ourselves beginning with a question. Now, the point to bear constantly in mind is the end in view; we are actually seeking an answer, and therefore the question must be one capable of being answered. It is no use, for example, asking if life exists on yet undiscovered planets. As there is no possible method of arriving at an answer, the question is meaningless in the sense that there is no meaningful process that can be followed to settle it. It is not a sensible question. Again take a point very frequently raised in philosophic discussion:—

"How can you prove that the world exists?"

Here again we see that proof, to be proof, must not presuppose existence. What kind of a proof can it be, therefore, that does not

presuppose its own existence? Accordingly by replying with the question, viz.: "What kind of a proof can be regarded as satisfactory?" We automatically expose the hollowness of the original question. It turns out not to be a sensible question at all, but a meaningless collection of words.

Here, then, is the kernel of the matter. The question and the answer cannot be separated from each other. Any fool can ask a question, but he only who knows the answer knows also how the question ought to have been phrased in order to point the way to the correct answer.

Does this mean, then, that we are landed in an impasse? If we cannot ask the question before we know the answer, how can we proceed? Not at all. The history of science, for example, is the story of rather foolish questions, the story of the discovery of semi-foolish answers to them, the reconsideration of the question in the light of this answer, and so on, step by step, to and fro, until finally the scientist finds exactly what question he should have asked in the first instance in order that it might have been answered sensibly. The answer and the checking against practice enable the question to be restated, reanswered and rechecked. It is a process of trial and error, where each error is used to direct us more surely, and each trial tests the improvement in our direction.

Here we have been considering one stage within a journey in thinking, but notice that what we said about the journey itself applies apparently also to the partial stage or phase. The stage was itself not completed until it had passed through a series of sub-stages, of successive questions and answers gradually being refined by trial and error, until the climax is achieved. Does the answer, then, just fit the question, and the question just fit the answer? As we shall see, this is not the case. There is always at least one difficulty left over, and it is in the attempt to resolve these that we pass over to the next stage of the thinking process.

Instead of dealing with this matter in general terms, let us try a case and study it. What shall I think about? It is my interests that focus my thoughts; I must therefore say what I am interested in. War? Very well, let it be war.

I begin by asking myself a question. *Why am I interested in war?*

I check this question against my avowed purpose, to think of war, and it seems that the answer required for this kind of question may lead me on to talk mainly of my interests and not of war. For the moment I am not interested in my interests. Accordingly I don't bother to pursue this question, but proceed to amend it. Thus:—

What is it in war that interests me?

Note the difference. I am already on my guard not to interpret this as an inquiry simply into my interests, but rather into war. Now, as it was I who suggested the topic, it is therefore I who must now provide the information required; I am not asking what attracts or repels me in war, but what it is that I am "worrying about." One worries about a difficulty, and how to resolve it. Two facts stare each other in the face and seem to oppose each other, and yet they are both facts. So we worry about how to reconcile them. As thinkers we cannot abide two apparently contradictory facts without attempting to *understand* them. So what we mean by *understanding* appears to be finding a way of looking at both facts so that they are seen as consistent or natural parts of a larger background. *Understanding is resolving an opposition.* I have to state what I am puzzling about. It is very simple.

Why is it that a war nowadays seems to involve practically the whole world?

Apparently I am comparing wars of yesterday with wars of today. I must bring the opposition more sharply to a focus. Consider the facts. A war of, say, three hundred years ago, was simply an affair between two small contending armies, pitched battles in a field, and the great mass of the population went its way without much disturbance, visitors passing easily from one warring country to another. Nowadays the whole nation is involved, contending countries are isolated one from the other, and it appears to have become almost impossible to localize a conflict so that other countries do not get dragged in. These are my opposites and my query becomes: *How exactly has this happened?*

We have it now in focus. We have taken a long time to come to the point, but that is because most of us take these early stages quickly. We can do so if we isolate the contradictory factors and state them side by side. Nevertheless since we expect that this

discussion will finish up with a final question that will lead on to the next stage of the train of thought, we cannot be too careful in phrasing our queries. The more careful we are, the sooner will we reach our conclusion.

At this point of the discussion we have to beware of leading ourselves on a side issue by the lure of words.

Does the contradiction not arise, I question myself, because I insist on using the word *war* for what is in reality something quite different, viz., *Armageddon*? Very well, I will, if necessary, phrase the question thus:—

"*Why have wars changed into Armageddon?*"

I have silenced the word-monger and I am grateful to him because I have now a shorter and more sharply contrasted way of asking my question.

Now what kind of answer do I want? What type of answer will seem satisfactory to me. I had better look at war and at Armageddon, as we are calling it, to see exactly where the *differences lie*. Suddenly another idea intrudes:—

"It simply didn't occur to the combatants to make wars on such a large scale in earlier times"—is a possible answer. This is unsatisfactory, however, because I would want to know why it never occurred to them. In any case they hadn't sufficient men and they hadn't sufficient war material. And while we are following that line, could they have fed more soldiers and moved them about over long distances? What about their transport facilities? What about their opportunities for finding out where the enemy was; and, again, what about their methods of fighting? I may not have been satisfied with this answer, but it is useful, for as soon as it is posed a whole volley of counter-arguments and extra difficulties are automatically fired out to expose the folly of the answer. Against the argument we place a set of counter arguments in the form of facts and possible facts that we ought to examine.

I can now state with slightly more definiteness the kind of answer that will satisfy me, and if I can only do this carefully I will have got a stage further in the analysis.

"The answer that will satisfy me," I reply—and here I must be cautious because it has just struck me that there may not be one

simple answer—"will be one that shows, for example, that increased scale of wars and battles became *possible* and *inevitable* as a result of other changes; for instance, the invention of new war materials in a very wide sense."

Here, at any rate, we have something positive to test. Let us check the suggestion contained in this, against the facts. We begin to collect data, and to place them in contrast; war material, say, at the time of the English Civil War, 1645, with corresponding material at the time of the 1914–18 world war. Thus:—

Muskets with a rough range of a few hundred yards and inaccurate in aim, compared with modern rifles and their deadly accuracy at a range of a mile. Cannon, firing balls that bounced along the ground in the hope of doing damage by direct impact at a distance of less than half a mile; against the modern "Big Bertha" and long-range cannon, firing from a distance of fifty miles if necessary.

Swords and lances; against poison gas, flame throwers, trench mortars, aircraft, aerial bombs, high explosive and poison gas shells, tanks, machine guns.

Messengers on foot and horseback; against observation balloons, aerial reconnaissance, telephones, telegraphs, and wireless.

The beleaguering of a town by a small army of men; as against the economic starvation of a country of the size of Germany by warships, submarines and sea mines.

These are a few of the vital material differences that immediately suggest themselves as soon as the two types of war are contrasted. Other features, such as tactics and strategy, also are different, and the question why they are different is at once explained in terms of these same material factors. For example, the Napoleonic Wars were conducted in massed formation by soldiers in distinctive coloured uniforms. We have to compare this with soldiers in khaki or dull grey to render them as indistinct as possible against the accurate fire of rifles; scattered formation to diminish the effect of shell fire; and trench warfare to the same end. To each new technical development in attack, a new technical development in defence. With the invention of poison gas came the defence of gas masks. With the invention of bombs and shell fire of the high explosive type came the counter defence of dug-outs and bomb-proof shelters. To each deadly ques-

tion its answer. Again we contrast the commissariat. In earlier days the slow transport of food, ammunition and equipment by horses and the ransacking of towns for food, has to be compared with the carrying of these things by motor transport, by aeroplane, and by sea in fast ships, providing tinned meat, bottled fruits and jams, drugs, and hospital equipment. Thus a highly efficient factory system and modern mechanical methods in industry have now made it possible to produce shells, rifles, guns, bombs, and other forms of munitions (including foodstuffs) in enormous quantities.

Our answer seems now clear. It has followed from the facts as soon as our questions and the preliminary answers suggested just what kind of facts to look for. The difference in the scale of modern warfare compared with that of three hundred years ago appears to lie in the change that has occurred in the industrial capacity of the countries concerned and in the large degree of mechanization that is associated with it. This is putting it shortly. We have now at least a partial answer to the query:—

Why have wars changed into Armageddon?

Because of the new possibilities opened up by the machine age for waging war, in virtue of the grand scale of modern industrial organization; and remembering that war seems to be the only activity in which science is used to its fullest extent, we realize that all these death-dealing inventions are brought into use because neither side dare risk losing any advantage. It should now be possible, if we cared to do so, to construct a series of pictures in ascending scales by taking the successive wars of history and relating their magnitude and intensity to the technical weapons of destruction and defence at each period; and associating these again with the stages of industrial development. More than this, we should be able to see how tactics and strategy have been forced continually to readjust themselves as the technique of destruction has transformed the problem from one stage to the next.

Have we finished the first stage of our venture?

Not quite. There still remains a part of the question unanswered.

Why do wars become world-wide?

The answer we have found so far, satisfactory as it appears for one portion of our dilemma, leaves another part still open. We can still

envisage two nations carrying on a large-scale war alone, without other nations interesting themselves in it. Yet it is a commonplace of recent history that there is a tendency for other nations to be dragged in. We are still left with a contradiction to be resolved, but we raise it now with a newer understanding of the crucial factors in the situation and a new-born sense that we can deal with it. Once more, therefore, we give a tentative answer, suggested by that just found:—

"Other nations become involved because these other nations or groups in them are intimately concerned in the technical and industrial organization inside the warring countries."

We can now proceed to examine this tentative answer just as we did in the previous case. We collect data and check and amend the statement in the light of these facts. Out of our previous analysis there is left this partial contradiction, this unresolved puzzle. It becomes now the starting-point for the next stage, but it becomes a problem whose aspects are already illumined by the conclusions of the previous stage. We enter it already with greater understanding than we possessed when the original problem was posed.

For our purpose, therefore, it is unnecessary to pursue this particular topic any further. It has been chosen at random as an illustration only, and it remains for us to draw our conclusions as regards the accuracy or otherwise of the process of thinking we outlined in the earlier pages of this chapter. We would be rash if we attempted to maintain that the argument developed above was, in all senses, logically unassailable and accurate to the last detail. We have been dealing with a broad subject, posing a question at a certain general level of understanding and explanation, and we have dealt with it at that level. Innumerable detailed questions can be raised in connexion with each one of the separate items—for example, those mentioned as modern technical developments—but the conclusions arrived at provide for us a background, and a set of guiding lines, for further extension to the next phase, or for more detailed study of this one.

Let us review once more the salient features of the method we have followed in this chapter.

1. Our interest focuses our attention on a problem.
2. A problem appears to be a situation in which two ideas or two

or more facts, accurately verified, when interpreted stand in opposition or in contradiction.

3. The issue raised is stated as carefully as possible in the form of a question.

4. The question is examined to ascertain that, in the form in which it is couched, it is sensible; i.e., it is answerable.

5. A counter question is posed, "What kind or class of answer is expected?"

6. This enables a tentative answer to be posed.

7. The examination of this answer, alongside the available data, shows that it is deficient in certain respects.

8. This deficiency allows a new question to be posed.

9. This suggests the accumulation of new data and allows a new tentative answer to be suggested.

And so it proceeds.

At any stage we may stop to reconsider the steps taken earlier, in the light of the later development. Finally, there emerges a viewpoint, a reconciling interpretation, that unifies the apparent contradictions.

It is worth while examining this process in further detail so that we may become conscious of what is involved in some of the steps. We notice, in the first place, how necessary it was to recast the question as originally posed, otherwise we would, if we had remained true to its form, set off on a search for the factors that aroused an interest in war, rather than in the problem of war itself. Here, then, we were striving to adjust the phrases to the precise ideas, a process analogous to what we have already indicated in the chapter dealing with words, ideas and objects. It is, in fact, an extension of that process. Here we have three elements in the situation: There is, first the proposition or question, the actual words used. There is, secondly, an actual situation, a changing process to which the words relate in detail. There is, thirdly, the idea conveyed by the proposition or question about the situation. If we set it down in this way:—

PROPOSITION		MEANING of		DATA
or	$\rightleftarrows$	PROPOSITION	$\rightleftarrows$	or
QUESTION		or QUESTION		SITUATION

we can trace the sequence of thought by watching the changes made in each of these factors as we proceed. We began with a question,

and compared its meaning with that intended. This forced us to alter it. We compared this with the facts as we know them, and this compelled us to alter the meaning we could give to the problem. Accordingly, we were then driven to readjust the statement of the question to correspond to this meaning, until finally we reached a stage at which the proposition suggested by the question and the meaning "clicked" with the data, or at least with a considerable part of the data. We have swung backwards and forwards between proposition and data in this diagram. We were then ready for the next stage. We begin with a new proposition relevant to that portion of the question still unexplained and based on the idea that had emerged from the previous discussion, and so on.

I have used this word "clicked" deliberately to describe a certain feeling aroused when we succeed in fitting the correct set of words to the meaning we intend to convey about the set of data. In this sense we have to recognize that thinking is not a process divorced from feeling. We clinch an argument with a feeling of satisfaction, and unless we are satisfied, it is obvious that the stage of the discussion has not been completed.

We shall see in a later section of this book how all this is related to what is called "the obvious" and to "logical thinking," but for the moment we should realize that we have been bringing to play something more than the mere checking or comparing of one thing with another, or of an idea of a thing with the thing itself, or of two ideas. We are continually making inferences or "seeing" implications We see that B is a necessity of A, or A implies B, or A involves B, and in the seeing of it we are driven through the obvious to the next stage. In doing this we are sensing something, experiencing something, and applying a power of recognition and discrimination similar to what we are accustomed to do with our eyes, ears, tongue and fingers. It is because we do not usually think of the brain in this way as also a sense organ that we have no special terms in which to express this process. So we borrow metaphors like "seeing" and "feeling" and "clicking."

There is yet another aspect of this question to which attention must be directed at this stage, although we shall deal with it also in greater detail in the next chapter. In very general terms I have described a

process of mental behaviour, and exemplified it in a particular case. Does this establish its generality? How can I tell that other people can also think in this way? Actually, I do not put it forward as a necessarily accurate description of how everyone thinks, but it is a method that everyone can try out for himself. As we shall see, the significant feature of a general law is not its unrestricted truth in some static everlasting sense, but the possibility of its being used in a wide variety of new cases.

It would seem desirable to conclude this chapter by giving some short indication of the method adopted by scientific men in their specialist thinking. I have restricted myself to their specialist thoughts because it can hardly be maintained that outside these spheres they necessarily carry forward the procedure with equal rigour.

Here the same general plan can easily be seen. We may represent it diagrammatically as follows:—

$$\begin{array}{c}\text{Scientific}\\ \text{Law}\end{array} \leftrightarrows \begin{array}{c}\text{Theory of}\\ \text{Process}\end{array} \leftrightarrows \begin{array}{c}\text{Experimental}\\ \text{Data}\end{array}$$

It is impossible to say where a scientist begins. His data, for example, are not only what he has himself found, but the accumulated data of other experimenters in the same and allied fields. A collection of this *data* is brought together. The principles that guide him in the choice of what is and what is not relevant are referred to in the next chapter. In bringing them together he is already working on a tentative *theory*. This enables him to propound a tentative *law*. Once this is carefully stated, his next objective is to test its truth by a carefully arranged experiment. The results—the additional *data*—force him to reconsider the *theory* by means of which he had grouped his data together. Thus he finds a more specific and perhaps more carefully worded *law*, and so on. If this is compared with what we have already set out for ordinary thinking we can see that there is no inherent difference between the two processes.

There are two minor points, however, that might be noticed. Almost invariably the scientific man is concerned not with general qualitative statements such as we were compelled to make when discussing the subject of war, but with accurate statements in terms of measurable quantities. Vague talk is of no use to him. The second point is that it is rare for a theory as first outlined to rest only on the

evidence of the immediate data alone. There is usually a great deal of circumstantial evidence. The theory, for example, may be one rather like others that have been found successful in the past; or it may be a development of an already accepted one. The cogency of this can be seen if we realize that were a theory to be propounded that contradicted one already well established, the facts on which the new one rested would in the first instance at any rate be regarded with grave suspicion. They would be checked and re-checked.

Scientific thinking, scientific practice, and the precise formulation of laws have to be seen as three elements in a unified scheme of development. Science is not a set of theories, originating in the fertile brains of super men, not a code of physical laws handed down by a scientific Moses, churned out in stellar space, nor is it simply a laboratory textbook for the conduct of certain experiments. Science, like thinking in general, is a part of human history; it is the story of man forging an instrument to discover what can be done with the world. The three categories we have set out—Law, Theory, Data—are simply three parts of that process of making history in which all human beings partake. This is what is implied when some writers use the very expressive phrase—the unity of theory and practice.

Now the successive stages in the development of science also bear a very close relation to the detailed steps in the thinking process that we have been discussing. Thinking, we saw, proceeded in levels, the completion of one stage enabling us to pass to the next at a new level of understanding. Take for comparison the position in science fifty years ago, in relation to our knowledge of the structure of matter. Every schoolboy knows the evidence relating to the chemical combination of substances in exact proportions by weight that is used to justify the atomic theory of matter. From that theory a host of scientific laws arose, and whole collections of data, previously unrelated, were seen to fall together into a unified scheme. The Russian scientist Mendeléef, for example, produced his Periodic Law, showing that the elements could be arranged in a systematic order in rows of seven according to their increasing atomic weights, and that when this was done all known substances of this nature fell into columns, natural groups or periods showing closely similar behaviour in many respects. Mendeléef's Periodic Table may be regarded as the scientific

statement or proposition summarizing all the fundamental knowledge on the subject up to his time. It was the end of a phase, the answer to a whole series of experimental queries, but it was not a complete answer. On examination, it disclosed a number of gaps that should have been occupied by elements, so far unknown, if the table were to be complete.

Thus the next phase began with the questions:—

"Can these unknown elements be discovered? Do they actually exist? Why have they not been detected in the past?" and the kinds of answers that were to be expected were immediately provided by the table itself. The table could tell us very nearly what their weights should be, whether or not they would be metals, with what kind of substances they would combine; i.e., whether they would easily form chlorides or bromides or oxides and therefore whether it was likely they would be discovered in Nature in the pure state, or in the form of such compounds. It could tell very exactly how soluble these compounds would be in various liquids. It was able to give even a more direct indication of where to look for them. For the properties of some of them, in these respects, were so like those of their neighbours vertically and horizontally in the table, that it was just possible that the substances classified as their neighbours were not really pure, but might contain some traces of the undiscovered elements because the experimental methods of separation had not been fine enough.

Here, then, we see one phase or era of scientific advance closing with an almost comprehensive answer, out of which there was urgently thrown up a whole battery of questions, problems, contradictions to, or denials of, the completeness of the answer. To these questions the kind of answer, and where to seek it, was indicated by what had already been achieved in the previous phase.

Science was immediately lifted to a new level. There followed the discovery of radium, uranium, polonium, etc., a series of new metals that were bound to possess properties of a peculiar type because so far they had remained undetected. These are the so-called radio-active substances, and the new phase of modern sub-atomic physics had been set into being. Quickly in succession came the discovery of radio-active emanations, electrically charged particles of various types that were shot out from these new metals, X-rays, electrons,

protons, photons, neutrons. The old atomic theory that had led to this outburst of feverish activity in the early part of this century could no longer maintain, within its form, the mass of new information that pointed inevitably to a fine structure to the hitherto indivisible atom; hence the quantum theory, the present answer to the innumerable queries posed since that day. At the moment it reconciles the apparent contradictions between the data on which the older theory of whole atoms was based and the newer knowledge that exposed the fact that the atom is not an indivisible whole. The theory is itself incomplete, but it is the present answer to the present phase.

This has been no mere digression into the history of a particular epoch in science. It is a sample of the large-scale movements that have always taken place there. The same characteristic outlines can be seen at almost every stage in its history, and in any one branch. It is exactly analogous to the process of thought and action we have outlined in the case of individual thinking.

In conclusion it is worth while noticing precisely in what way the passage to the higher level occurs. If we refer back to our three-fold categories: proposition or law—ideas or theories—data—we see that in all cases we tend to retain the ideas or theories and the proposition as long as possible, until we are driven to relinquish them by the accumulating data that can no longer be fitted into the propositions that express these ideas. The driving force comes from the data, the material world about us, and the struggle is to fit our ideas and our language to the accumulating data. Finally, the contradictions between the ideas and the propositions on the one hand becomes too great for us to remain satisfied under the gathering pressure of the data. Thus the struggle between the verbal and mental form, as against the facts or content it is striving to accommodate, becomes too intense. The facts gain ascendancy and the verbal and mental forms melt and set into a new mould.

Individuals differ considerably in respect to their sensitiveness to the cogency of facts, or what is now seen to be identical, in respect to the tenacity with which they hold to the verbal and mental forms. They have various melting-points, but nevertheless it is the recognition of this process that offer us the possibility of conscious method in thinking of adjusting mental and verbal form to concrete reality.

CHAPTER SIX

THINKING OF NATURAL LAW

IN THE PRECEDING chapter we have tried to set out in simple terms some of the more elementary steps human beings take when they are thinking. My purpose in doing so was to make the taking of these steps a conscious action on our part, so that they may become objective, open to examination, criticism and refinement. It was intended to be not so much a description as a statement of what to do and how to use the method implied in it.

We must notice, however, that I have implied, rightly or wrongly that such detailed steps as I have outlined apply equally to you as to me. If you were able to say: "Perhaps you think in that way. It certainly is quite meaningless to me," it would be reasonable to assume that I had not described a general method, but at best a personal idiosyncrasy. Instead of explaining *our* thinking behaviour I would have been concerned with *my* thinking behaviour.

I want to underline these two characteristics to which I have referred, viz., the suggested *generality of the statements*, and the fact that the statements are really offered as *prescriptions for action*; for these are the two fundamental features of what are called *laws* in science.

A law covers a wide range of cases; it holds for a class of case. The law of gravitation, for example, states that every particle in the universe attracts every other particle with a force depending in a definite way on their distances apart. Thus the law applies to the class called "particles of matter"; it does not apply to colours, or to ideas, or to thoughts. The law, properly stated, indicates the class to which it refers. It would apply to every particle of the table I am writing on, to the elements of the water that flows through the bathroom tap, to every particle of the sun, but not to my feelings or to intervals of time.

For the class of substances called gases there is Boyle's Law, which asserts that the greater the pressure applied to a mass of gas, the smaller the volume it will occupy; there are corresponding laws for liquids, and for solids; there are laws for electrified particles, and for

electric currents, laws of magnetism, laws for the passage of heat, and for the reflection of light. Each law has a limited but at the same time a general application. It is limited to apply to a particular class, but it applies generally to every member of that class.

That at any rate is the intention of scientific men when, after elaborate investigation and experiment, they finally formulate their law. Now we have to realize that such a study is itself simultaneously twofold. The scientist seeks the class to which the law is to apply, and seeks the law to apply to the class. The process is exactly analogous to that involved in the previous chapter where we sought a mutual adjustment between question and answer. Take an illustration. We talk so glibly, nowadays, of wireless waves, and light waves, and electromagnetic waves, and the speed of these waves, that we rarely appreciate the long and elaborate series of experiments that had to be carried out before it became clear that there was a something resembling a wave with a speed at all. When you switch on the electric light is it not the most natural thing in the world to suppose that the illumination is everywhere in the hall instantaneously? If it is dark at the other end, does the light keep on gathering there? Why imagine that it travels or takes time to travel? You switch the light out; isn't it dark everywhere instantaneously? One tends to think of the light as being everywhere at once, but being greatest at the incandescent filament, departing and coming with its brilliance.

When Römer decided that light really took time to travel, that there was a *speed* of light, it was one of the greatest moments in the history of science, for he was separating out a measurable quality of the light, its speed, whose existence had previously not been dreamt of. Many years after, Hertz, by setting up an electric discharge in a condenser at one end of a room, and watching to see if another condenser placed at the opposite end also discharged itself, likewise showed experimentally that electric waves passed outwards from the one condenser to the other with a definite speed. These are the wireless waves with which we have become so familiar nowadays. These people were all busy showing that there was a quality in common between a whole range of different kinds of events, electric discharges and oscillations, and light, and even mag-

netic disturbances, so that they could be classified together in respect to this quality. Clerk Maxwell, applying a theory of the composition of such waves, showed that they should all travel with the same speed, the speed of light. When these speeds had been measured and found to be equal, we had a law applicable to a class. The law was to the effect that all electromagnetic waves travel with the same speed, viz., 186,000 miles per second.

We see then that the first step was to seek the class to which a law could apply, and then to seek the exact law, if it existed. If it didn't, the class would have been of no interest to scientists. They look for classes which behave in a unifiable and measurable way. The things studied have to fall into a class, and their behaviour in another class. Now it is worth while noticing that as a matter of fact Römer had already carried through this process to which I am directing attention. When he asserted that light had a definite speed, and he measured its speed approximately, he was thereby already grouping together under one head all the modes of producing light. To him it was immaterial whether it was a burning taper in his hand, a flaming beacon on a distant hill, or the sun ninety million miles away. He classified them together as emitters of *light*, and this quality that he thus used to define his class could be, he asserted, the subject of a single statement true for all members of the class. By concentrating on *light* and the conditions under which one could detect it, he formed a scientific class, and by establishing a general statement about that class he had formulated his law.

This he did because he had a purpose. He was interested in something that was puzzling him, a real contradiction, the apparently erratic behaviour of Jupiter and its moons. According to his calculations and observations they seemed to be getting into the wrong places. If these places were correct, then a whole series of other calculations would be wrong, and a whole series of other observations would contradict each other. Immediately he realized that light took time to travel, and that by the time he *saw* the moons they had already moved to a different place, the apparent contradictions were resolved. The whole process literally was seen in a new light. Notice again that what we have stated in the last chapter as the characteristic of thinking, the resolving of apparent contradictions, is again fol-

lowed in detail here by Römer; and has been followed in fact at every step in scientific progress.

When we examine the law that all electromagnetic waves travel with the same speed, we notice that it appears to have been achieved in a comparatively simple way. The original class of occurrence with which Römer was concerned was that showing "visible light." In the later development a wider class was defined embracing this class but covering occurrences not previously associated with light. This wider definition could not of course be made until a much later stage in the history of science, not before a whole series of studies had been experimentally conducted on electric discharge and electric oscillation. The *same law* was shown however to apply to a *wider class*. That is one method of generalization. Sometimes it works in the opposite way. *A wider law* is shown to apply to the *same class*, as, for example, when Einstein propounded the theory of relativity and produced a generalized gravitational law.

How can a general law ever be securely established? When we have a set of facts, or as they are called data, and a general statement is made that purports to apply to every member, every item of the data, we can verify its truth in each individual case. If we have a group of one hundred railwaymen, and we make the general assertion that they are all colour-blind, in every individual case we can apply tests to discover, for example, whether each member of the group fails to distinguish between red and green.

The general statement is possible because to test its truth we can turn to every member of the class. The class can be exhaustively tested. If, on the other hand, I make the assertion as a general proposition, or as a general law, "All railwaymen are colour-blind," I am faced with something quite different. If it asserts that all present railwaymen in this and every country are colour-blind, I can dismiss the proposition as soon as I come across one who is not. If I find that all present ones are (which they are not, of course), but read the proposition as implying that all present railwaymen are colour-blind and all future railwaymen will be so afflicted, it is clear that I can never hope finally to establish the proposition on the same basis as it can be established for the restricted or enumerable group

Now the curious point is that natural laws appear to be of this

kind. How can we ever show that the law of gravitation applies to *every* particle in the universe? How can we ever be sure that Boyle's Law applies to *every* mass of gas? That *all* electric currents in the future will follow Ampère's Law, and that heat will *always* pass from one conductor to another according to the heat laws?

It is clear that all we have to go on are the facts. But what are the facts? Now the facts are not simply a set of data which have been seen to fall into a class and, having been examined, satisfy the law as stated. That would in one sense be all the facts if we had tested every member of the class, but general laws in science are not very usable or useful when they are of this restricted nature. The key word in this situation is *useful.*

In seeking to establish a general law it is not simply idle curiosity that prompts us. To suppose that science has arisen simply as a result of pure inquisitiveness in man, is to misread its whole history. Individual scientists are of course inquisitive and interested in the world, just like other people, but this does not in itself give science a greater importance than stamp collecting. Science has been developed, and has come to occupy the important place it does in society, because it has been found socially useful, and its use lies in the fact that when it has discovered a general law, or supposes it has discovered such a thing, it tests out the truth of the law by finding a use for it. This it does by trying to tell in advance what will happen in certain circumstances. It is used in the first instance for making predictions. The predictions are not confined to abstract geometry or to celestial mechanics. They enter into every aspect of engineering and industrial technology. Science is the modern substitute for prophecy. If a general law in science cannot be used for prophecy, it is not of much consequence.

When we state, for example, that common salt when treated with sulphuric acid gives off hydrochloric acid, we state it on the basis of a large number of experiments directly and indirectly constructed to test the truth of the statement. Conviction comes with even greater force however when the statement is used to design an industrial plant to produce hydrochloric acid on a large scale; or when some other experiment gives a result already anticipated on the basis of the supposed fact about hydrochloric acid. Both the

theory and the practice of science are knit up on all sides with an interlocking mass of experiments, all depending one on the other and each continually being tested by practical prediction.

This, then, is the second characteristic of a natural law to which I made reference in the earlier part of this chapter. First it is a law describing the behaviour of members of a class, and second it is a prescription towards action. Its generality is tested in its use. When therefore we say that Boyle's Law applies to all gases, what we mean is that if for some purpose you have to use a gas and you are concerned with its pressure and its volume, you had better try out Boyle's Law. If you have to inform pilots when they may find high water or low water at a particular port you tell them to look up the Nautical Almanack. That is the practical form in which the pilot, perhaps unwittingly, applies the law of gravitation. The practical form in which the scientist applies it, is to compile the Nautical Almanack on the basis of the law that the attraction of the particles of the sun and moon are, along with the rotation of the earth, responsible for the rising and falling of the tides.

The process of passing from a statement about particular cases, to the general statement that a whole class of non-enumerable members follows (or can be examined by) the same law is usually called *induction*.

Most books on logic present induction as a sort of illegitimate attempt to pass from a series of particular cases to a general proposition. As regards its application to science such a statement isolates it from one of its prime functions, the part it plays in the active pursuit of science.

Induction is clearly inherent in the method of science, but we must not jump to the conclusion that science is therefore a sort of illogical proceeding. Its laws, as we have seen, are not merely general all-embracing statements or logical formulæ, but pieces of advice, and because they are pieces of advice they offer us what we have continually demanded here, within their limits a method of helping us to decide what to do with the world.

Science tells us how the world has been handled successfully in the past; it strives to crystallize that information by stating it in the form of concise laws of behaviour; and in effect it says: "When you

also come up against a situation like this, base your actions on the cream of our experience. You will find it embodied in this law. Do not regard it as final, use it rather as a method or as a plan, and if it does not work let us know, for our object is to get a law that does work. If you will use it in this way, you will use it scientifically. It is not simply a static, logical, proposition."

It is usual to contrast induction with deduction. Here the process is reversed. A certain proposition is *stated* to be true for all members of a class. Special information about a particular object shows it must be regarded as a member of that class. We declare that the general proposition applies to the member. Stated in this bald way deduction appears a rather useless procedure. If the original class is limited in extent, then we already know that the general statement can have a validity only in virtue of the fact that it has been tried out in each particular case. To deduce in these circumstances that it is also true for one of the members of the class is then simply re-asserting something we know. It becomes a mere game of words. If the class is unlimited in extent, then deduction applied to a member not already among those tested becomes equivalent to what was done under induction, viz., using the general principle as a line on how to treat the new member.

In neither of these two senses does deduction appear to add anything to what we have already discussed. Yet in another way however deduction plays a very important role in science and in logical thinking.

To some extent we have already dealt with it when we were discussing how classes were formed. Consider it in this way.

When a law is stated about a class it takes the form:—

All members of a certain class defined by one characteristic have also another characteristic. For example: "All electromagnetic waves have the characteristic of moving with the speed of light"; or stating it entirely in terms of classes:—

"All members of the class electromagnetic waves are also members of the class of processes that change with the speed of light."

Put in this form we must remember that there must be methods of identifying the two classes. These are in this case the experimental methods of science, but they may also be the ordinary methods in

common use among non-specialists, when the subject is not a specifically scientific one. Again, when put in this form the question is immediately raised whether the two classes are identical in extent. We might ask, for example:—

Are there any things moving with the speed of light that are not electromagnetic waves? This suggests a line of inquiry and further study. If the answer is in the negative, then we can reverse the statement with equal truth and say:—

"All things that move with the speed of light are electromagnetic waves."

The two classes we have referred to become identical. This is what can be called the *necessary and sufficient* form of the law. Any object possessing the one characteristic necessarily possesses the other. It is sufficient to possess one in order to possess both. The two classes are co-extensive.

If two classes be co-extensive and if an object be identified as being a member of one class then that object is also a member of the other. This is, in reality, a process of identification and is known as *deduction.* In this form it is a method that is practised in all branches of experimental science. It is also the basis of all mathematical investigations. For that reason mathematics is frequently referred to as a deductive science.

The form in which we have stated the principle used in deduction is however not the most general. In discussing the derivation of classes from an individual object, by separating off for consideration only one quality, we pointed out the twofold character of such an object. First it was to be regarded as typical of a class or a series, and secondly we could reverse the procedure and specify the object, up to a point, by detailing the classes to which it belonged.

This twofold mode of approach is nothing more than the presentation of induction and deduction again.

Accordingly we can state deduction in this form: *If two or more classes be only partially co-extensive, and if an object possesses each of the defining characteristics of each of the classes, it is a member of the class common to all.*

Let us illustrate with a simple case in geometry. We start with a circle and we want to find its centre, the latter being defined as the

point which lies at an equal distance from all the points of the circumference. Fix A, B, C, any three points on the circle, and concentrate our attention on the points A, B alone. There is a class of points that are equidistant from A and B. They all lie on a straight line at right angles to the line AB through the midpoint of AB. But the centre being equidistant from all points on the circle must therefore be a member of that class. In the same way the centre must be a member of the class of points on the straight line lying at right angles to BC and through the midpoint of BC. Thus the centre is a member of both classes. These two classes are not co-extensive. They have in fact only one member in common, viz., where the two lines meet. This then is the centre.

Or again consider a case from the field of chemistry. We are given a certain clear liquid in a tube. We have to detect what metallic compound is dissolved in it. We add a little hydrochloric acid. It remains clear. We conclude that the substance present does not belong to the class that forms insoluble chlorides. This eliminates silver and lead at least. Through this we bubble the gas called sulphuretted hydrogen, and a yellow deposit or precipitate is formed. We conclude that the substance belongs to the class that has a yellow sulphide insoluble in an acidic liquid. This cuts out everything except cadmium and arsenic. We filter off this precipitate, add warm water and a little solid ammonium carbonate. The precipitate disappears. We conclude that the original liquid contained arsenic. This is part of the regular chemical method for analysing a substance to discover which metals are present, and the essence of it is simply that by a system of cross classification we are finally led to the conclusion, from our knowledge of arsenic, that it is the only substance that falls into the various classes indicated.

It may be said that a great deal of this is commonplace in all systematic work, and too obvious to be worth stating. For instance the statement of what we mean by deduction given above seems almost a truism. Why give it a special name? In the first place it is worth giving a special name, if indeed, by so doing, we become conscious of the steps we take in any logical study. If what we have stated is an essential step in any investigation, and the illustration with the circle is one of the simplest that could be given, then the

fact that when stated it appears obvious is itself evidence that we have reduced the treatment to a description of fundamentals. For consider for a moment what we can mean by the assertion "It is obvious that," etc.

Every argument when followed closely, if accepted, step by step, is clinched systematically by a feeling of consent, of admission, of acquiescence. "Yes," we say "yes, go on" and then "yes," again, until the final climax when we find we have agreed to the whole argument. It may happen nevertheless, that we have accepted the argument, step by step, and yet when the final statement summarizing the whole is made, the same sense of conviction is not by any means present. Each elementary step has been reduced to the obvious but the whole puzzles us. There is a new quality in the whole, absent in each detail.

These are just the two stages or levels of thinking to which we have already made reference, showing themselves in yet another way. Each step in the argument leading up to a conclusion has to be made so small that each in itself is reduced to the obvious. But it is a step forward; it is a process of change in thought, not a set of static steps. If we appear to reduce it to the truism that A is A, at the same moment it also becomes something else. Each step is tiny enough for us to mount, but they are steps that we *mount*, steps up which we *move*. If in this way we ascend to unaccustomed heights, we fear we are being led astray, that we have lost the control we felt we had over the whole situation, and we want to pause to become familiar with the new scene. It is only in an atmosphere of familiarity that we can agree and be convinced.

So also with the elementary step. We accept it when we can see all round it, when we can imagine or visualize all the possibilities, and when we reject them all except the one, the outlet to the next stage of the argument. The obvious is the recognition of elementary necessity, which is itself all we can mean by logical implication.

When we look at the obvious from this standpoint we begin to realize how much the cogency of our thinking depends in detail on our experience and on our imagination. An argument that will convince a child will not deceive a more mature person. How often have we not had said to us when we were young:—

"Oh, yes, this is all very simple to you because you don't appreciate the difficulties."

A young mind tends to ignore the complexities and interconnexions with the rest of the world. The mind becomes fixed on the objective, and other possibilities, either do not suggest themselves or seem of trivial importance compared with the crucial point.

"The point is . . ." we keep on repeating, endeavouring to direct the attention away from what are to us side issues.

Throughout we are continually limited by our restricted experience. What we alone have always seen to be the case we tend to take as necessities of nature. Take for example such a simple assertion that "one and one are always two." Is this a law of nature? Is it a necessity of thought? Can we avoid always acting on the assumption that this is so? And here let us dismiss what may become merely a verbal confusion. We do not define the word two or the symbol 2 as a shorthand expression for the phrase "one and one" or "1 and 1."

If we begin by thinking of our triangle of reference again, we will see at once that the symbols one and two have to refer to objects or processes. If we are to regard "one and one are two" as a natural law, let us then ask for what process is it natural and useful? As we have seen this is not to be distinguished from the question "on what basis does it rest?" The statement, then, refers to a process, one representing a combination. One entity is to be combined with another and equivalent one and the result of the combination is to be a group of these entities to which as a group, we have to apply the name two. More than this. The process is to be reversible. It must be possible to separate the group two into one and one of the original type. We shall see in a moment that we have already begun to tread dangerous ground. Suppose I take as my entities colours, blue and yellow. I combine the two colours. This I may do in various ways. I can place them alongside each other as if they were objects, and then the proposition is certainly correct. I can take them apart again, and I have the two colours. To do this, however, would not use the fact that they were *colours*. I need not have classified them as blue and yellow if I was going to treat them merely as objects. How does one combine colours? There are various ways of doing this, with the result that I get "one colour added to one

colour gives one colour." We state this usually as "blue and yellow give green" which is equally a law of addition. If we take as our measure the number of colours, we can state the appropriate law of addition in this case as one and one are one.

A dozen tributaries combine together to give one stream. If I consider the tributaries only as objects, of course, I will get the ordinary law that, one plus one, etc., form the group of tributaries "twelve," but if I am talking of the actual law of combination for the kinds of objects I have detailed we may state: one stream plus one stream, etc., etc., combine to form one stream. Two separate ideas, logically combined together as ideas to form a conclusion, another idea, is again a process that behaves according to the law "one and one are one."

The world is full of processes that would seem trivial if handled in the way in which one handles simple discrete objects. I combine together two separate groups each of five objects. The result is one group of ten objects but it is *one* group. One group and one group combined give one group. They may then give any number up to ten groups in this case, if the process is reversed. Only in a very restricted sense can we ever talk of a process being "exactly reversible." Before the reverse step is embarked upon the world is already different if only from the fact that the direct step has already occurred. Few actions can be undone. Nature moreover is very particular about the order in which the combination may take place. In combining objects it is immaterial which I take first. But the process in the eyes of the police is very different if instead of being shot and then dying, I die and am then shot!

We must not separate the law from the operation to which it is applicable.

Laws of nature do not stand on their own as abstract principles independently of the actual physical events that happen in the universe. They do not "guide" processes. It is from the processes that take place, that we have to discover the laws they exhibit. We tend to think of natural law as a sort of external force that compels material things, willy-nilly, to flow along in a particular way. This is indeed putting the cart before the horse. The universe in its perpetual state of flux is a changing medley and our laws have to

describe the world as it is. By our methods of classification we can see the groups into which these processes fall, just as we can see the categories into which objects fall. They are real categories and real classifications, because the objects and the processes do have the characteristics we have recognized, that have enabled us to group them. What we have to be aware of, is not too hastily to assume that, when we have succeeded in formulating a general law, it has a validity wider than the processes it can help us to understand. These we can be certain of, only by trying them, by searching them out. Not only have we to ask how wide is this law, but at the same time how narrow is it. In searching and trying, we bring our imaginative power to bear. In doing so we are continually extending the scope of the obvious, making the falsely obvious into the obviously false. All this has to be fitted into the picture of man's development sketched in Chapter Two.

Where does logic stand in relation to this? Logic is presented to us as a statement of the rules for reasoning, the process we follow in making correct inferences. Officially logic is not concerned with physically verifiable inferences. This must not be confused with clear thinking if by the latter we mean thinking in such a way as to arrive at conclusions that are borne out in practice. For the latter involves maintaining contact perpetually with the real world, and checking our conclusions against it after each mental excursion. Just as we have sought throughout these discussions to preserve agreement between idea and thing, the very essence of science, so in thinking we must seek perpetually to preserve agreement between process in thought and process in things. The logical sense we have, the sense of implication and of inference has been historically produced in us in this way by the impact of the real world upon us. It is the mental reflection of the behaviour of the universe, and in virtue of that it becomes an instrument of discovery to us. As the universe runs through its changes, so our experience widens and our logical sense becomes more acute. Thus our logic cannot remain static, but must needs keep pace with the universe. Logic cannot therefore be lifted as a subject, once and for all, out of space and time and material things, as a permanent grammar of thought; he who imagines he has written the grammar of any living language once and for

all is unaware of the nature of the changing, developing world.

There are some, however, who maintain this. Extracting a set of formal rules, they argue that by studying the "grammatical" structure, rules can be drawn up that are essentials of all thought, freed from the actual material to which they may be applied. Thus:—

All P is Q, all Q is R, and all R is S; therefore all P is S. Such statements are either tautologies, that is to say there are three superfluous names to the content of P, viz., Q, R and S, or else the truth of the proposition follows not from some absolute law of thought but from experience with groups of objects. It has a validity corresponding to "one and one are two" and has to be tested out in practice, as we have already seen in that case.

Can finality then in the form of a perfected logic ever be attained? Surely not. If the mathematician of one generation can point to the weakness, in reality the deficiency in imagination and in experience, in the proofs offered by the mathematician of the previous, how can he refrain from comparing also his own conviction that he has at last established his propositions beyond question with that of his predecessor who also felt the truth of his assertions with equal strength. Rather have we to see it as part of man's voyage of discovery in which as we acquire more and more knowledge of the world, as we tamper with the world to acquire this knowledge, we also acquire more and more understanding. We interpret its meaning more deeply to ourselves. Experiment, reasoning, and emotions, all play their part in the process, and we will make a serious error if we imagine that any one of these, at any stage of history suffices in itself, for the task as if it had attained complete perfection as an instrument of discovery. If the obvious lies indeed at the root of "proof" then it is the obvious for us human beings here and now; and human beings are what they are, rather befuddled members of the human race, groping their way forward to light.

CHAPTER SEVEN

MAN, AS CREATOR OF NATURAL LAW

WE USUALLY REGARD laws, in the legal sense, as codes, rules, regulations that govern or circumscribe our behaviour. It is this idea that laws "govern behaviour" that one finds so frequently also associated in people's minds with natural law. One hears the phrase "The universe is governed by a set of laws" as if the laws came first, and these were applied to previously static, unmoving masses of material; and thereafter as a consequence of the application of these laws the masses began to change their position according to a definite routine prescribed for them and from which they could not deviate by a hair's breadth.

This is a false view. In the last chapter we have been looking at this question in relation to the purpose for which the laws have been formulated by man, and the background of material from which the laws have been drawn. We have noted that laws are stated in general terms because they are, in that form, useful to man; and we have seen that the material from which the laws have been drawn consists of "changing parts of the universe." Since we never encounter anything that is unchanging, the whole notion of what might be called "unchange" is an imaginative one. Events appear to repeat, of course, like the rising and setting of the sun and appear to be the same or unchanged when they do repeat, but to say they are the *same* when, of course, they are different at least in the respect that they take place at different times is to give a meaning to *same* that is certainly not *undifferent*. All I am trying to emphasize is that change is an inseparable quality of the parts of the universe. Despite this, in making or formulating our laws, we talk about "the motion" of this or that as if we could separate the motion from the part. The law states the nature of the "behaving part" as an entirety. The law is formed in behaviour. If we separate the object from its behaviour falsely, we find ourselves later trying to reconcile them again by inventing a form of words such as:—

"The body has the *property* that it does so and so."

We ought rather to say that "this body in its behaviour can be

grouped with other bodies in their behaviour under the following general heading," and here follows the general statement of the law.

From this standpoint every element of the universe exposes its laws in its behaviour; it makes its laws as it persists, and there is no compulsion by some force *outside the universe*, whatever these words might conceivably mean. If it were *compelled* to behave it would also be *compelled* to exist and persist otherwise it would vanish!

I have stressed this point not only because it seems to be an accurate description of what actually occurs, but because if we approach the whole question of natural laws from this angle, certain difficulties that usually arise when we begin to inquire whether human beings also are "subject" to natural law immediately disappear. Human beings, like other objects, make their laws as they persist, i.e., as they behave. You and I have, or make our own laws. People say you are the kind of person who does so and so in such and such circumstances. They size you up, meaning thereby that they have classified you according to your modes of behaviour. They know some of your laws of behaviour.

In music or in harmony there are laws for the combination of sounds. There are laws for the combination of colour, and in an earlier chapter we set out to discover whether there are laws that describe or "govern" the process of thought. They are really tips to tell us how to examine and analyse a part or a process of nature by indicating a structure or pattern in the process.

I think we can assert that all such methods of analysis constitute the search for processes that have a structure or pattern, and a statement of that pattern in concise form. It is in this sense that psychologists and biologists talk of a "pattern of behaviour" among animals and human beings. Wherever we have detected a pattern of behaviour we have discovered a process or a group that can be made the subject of laws.

Now all such processes or patterns are not seen or found in sharply defined form. If we assert that all the colours of the rainbow are present in a sunset, this does not mean that they are always present in constant proportions. We have to allow for clouds, special atmospheric conditions, and so on. If I state that when the pressure on a mass of gas is doubled the volume will be halved, that does not

mean that I find this law exactly fulfilled in all cases. I find that sometimes it is rather more, sometimes rather less than halved, but in all cases I can also "put the blame" for the difference between what is found and what is expected, *reasonably* on various small factors that interfered with the course of the experiment. Perhaps a little of the gas escaped, perhaps the heat from my body made it expand a little, perhaps the temperature of the laboratory did not remain unchanged throughout the course of the experiment. All these peradventures, be it noted, arise from the interconnexions of the experiment with the rest of the universe, myself, the conditions in the laboratory, the climatic conditions, and so on.

When we talk of an *exact* law we are thinking of an idealized situation that is never fulfilled in the real world, a situation in which the experiment is completely isolated from the rest of the changing world. And because we think in terms of an *exact* law, these factors that we blame for the differences, we call *errors* of the experiment. In this sense it is impossible in the actual world of affairs to conduct an experiment without errors. Errors are real. They are evidence of, and give a measure of, the interconnectedness of the experiment with the actual world. So in reality when we want to use a law in practice we have to use it not as an idealized law, but with a margin to allow for this feature we have referred to.

Once we have grasped the idea that a natural law is not exact in the usually stated form, we are ready for a wider conception and use of natural law. If I state that 80 per cent of the population are not engaged in their normal occupations on Saturday afternoons I am stating a law of behaviour of a social group, but if you were to take a census next Saturday afternoon I should not expect it to give exactly 80 per cent. It might be as low as 75 per cent, or it might be as high as 85 per cent. I might then amend it by saying that it is 80 per cent *on the average*, or by saying "Every Saturday between 75 per cent and 85 per cent of the population are not engaged in their weekday occupations." The latter form would be exact if it were found that all cases fall within those limits.

Such a law is called a statistical law. It is a law of averages, but it can be stated in a form that makes its application precise by bringing the element of imprecision into the statement.

It is mainly a matter of custom that makes us state an ordinary physical law about a definite scientific process in exact terms, and blame the departures from it on the "error," while we state a statistical law as an average effect. They are in a sense both average effects; where the crucial difference usually lies is in this. With a physical experiment we can change, and, up to a point, control the experiment, choose the circumstances in such a way as to reduce the interconnexions with the rest of the world to the barest minimum. It is just with circumstances such as these that physical science is concerned. With most statistical laws, on the other hand, especially where they are laws relating to masses of people, we must take life as we find it; we must take the experiment as the mass of people conduct it on themselves.

It is because we do not usually control the behaviour of masses of people who are to *make their laws by their behaviour*, as other material things do, or because the mass of people do not control their behaviour *as a mass*, that we are prone to ignore the fact that they also show a pattern to which laws apply. Yet there are many individuals in the community whose business it is to extract just these laws and to act or advise action on a knowledge of them. Every time a budget is made for any country, an estimate has to be compiled on the basis of a knowledge of how people who have to pay taxes will behave in that respect, what proportion will successfully evade as the rate of taxation is made steeper. Railway companies adjust their fares and their train service on forecasts or predictions or prophecies of how the travelling public will behave. A great sports event takes place in a city. These companies have to forecast what the distribution of traffic and turnstiles and railway officers must be in order to cope with the congestion and incur the minimum of delay. Every telephone exchange has to know very precisely the laws of behaviour of its subscribers when they make their calls most frequently on the average, and how long on the average the lines are engaged if they are to satisfy their public. Every stockist of a goods store, has to have a very accurate knowledge of the buying behaviour, the likes and dislikes of his customers in order that he may not be left with a volume of useless goods on his hands.

The whole of our social life is interpenetrated with patterns of behaviour of groups of people that are legitimate subjects for expression in the forms of laws. Here, indeed, we see very clearly how important it is to seize hold of the idea that it is the object or process that exposes or makes its laws in its behaviour. Nevertheless, all we have said in the preceding chapter about these laws being couched in the form of classifications holds with equal strength here.

More than this. Laws are formulated as prescriptions for action. The illustrations given above show how simple laws of groups are used in business and social administration. Now man rests his claim to a higher level of life than the animal on the fact that he is not only conscious but self-conscious, and he uses the fact to implement that claim. Nevertheless, while he may be aware that other self-conscious beings make their laws in their actions, he is not usually conscious of the laws he himself forges. He is in this sense not fully self-conscious. In the same way when collections of beings make their collective laws in their mass behaviour, others may become alive to these laws and use them as we have illustrated. Only when such groups become conscious of the laws they forge and of the laws they can forge, and thus deliberately direct their activity, and use that activity in a collective purposive fashion, will it be reasonable to say that they will have attained the higher level possible for human beings in society. It will represent the first great step in the advance of mankind towards the control of his own future.

Finally, we can but point one stage further in this search for natural law. If there are laws for the behaviour of objects and simple physical processes, for human beings as individuals, for sectional groups in society, are there not also laws for the behaviour of whole societies? If we trace the history of man, as we have done broadly in Chapter Two, throughout its successive stages from barbarism to civilization, could we also say that it shows a pattern of behaviour, a definite law of change on the basis of which predictions and forecasts might be made of the kind of life man will create for himself?

We are not yet ready for the answer to this question.

CHAPTER EIGHT

THINKING ABOUT DETERMINISM AND FREEWILL

THE FATEFUL DAYS of August, 1914, saw millions of the youth of every country march in regular formation to systematic and routine slaughter. It was, in one sense, a dramatic if hideous culmination to an age of standardized production and of mechanized humanity. A century of industrial science and of scientific industry had succeeded in producing an environment in which the interests, the desires, the thoughts, even the actions of large masses of the peoples of the west were being shaped for them by forms of social organization of which they themselves realized little. In spite of the few outstanding cases of individuals who by their actions and their writings had shown that they had escaped from the deadening and cramping effects of their immediate environment, the great mass of the population remained frozen economically and intellectually within their class. The son inherited his father's position in society; generally the miner's son remained a miner. The mechanical determinism of the nineteenth century, with the whole weight of physical science apparently on its side, found here a suitable *milieu* for the acceptance of a fatalism that pictured the lot of man cast individually and collectively in a definite and inescapable mould. To this philosophy of despair the events of the war of 1914-18 contributed in no small measure. In the years that have elapsed since that date, events have conspired to underline such a philosophy in the minds of many of the younger generation. In a world of strife and turmoil, where human beings are regarded and have behaved as little more than regimented marionettes, obeying even to the death, the behests of a leader who himself indulges in speeches whose content can be predicted with astonishing accuracy, there is little sign that human beings themselves possess any of the characteristics to be associated with freedom in the individual will. Condemned to take his stand in an unemployment queue until whatever manhood he may have possessed has forsaken him; or possibly more fortunate, trained to efficiency in the arts and finding the doors of useful communal

service effectively barred to him; or even struggling for a few months desperately to revolutionize society in the immediate hope of creating a new heaven on earth, youth may be indeed excused for slipping back into an inescapable fatalism. Even those who have come to regard themselves as the fortunate possessors of a routine job, where hour after hour, and day after day are spent in the repeated performance of the same deadening task, must needs justify their position in life by an appeal to fate. It is in this bovine mood that many of the younger generation, and not they alone, regard the activities of those who would still strive to make of the world a place habitable for a self-respecting humanity. With such the hope of youth has early given way to the cynicism of old age.

Mankind is a mass of contradictions. The century that saw the age of the machine triumphant, that by its very success appeared to place the final seal on mechanical determinism saw also as a consequence the ascendancy of a new class of industrial entrepreneurs, that attributed its rise to individual foresight and force of will. It was this class that demanded as an inalienable right of man the freedom to use its will and superior judgment to its own advantage, subject only to the dictates of the individual conscience. If it was the age of mechanical determinism it was also the age of freedom of the individual will, and because these two philosophies co-existed side by side within the same social framework, in spite of their obvious contradiction, they probably did in fact each represent a partial truth.

That there are aspects of nature subject to mechanical law, the whole history of science bears witness. If the test of determinism rests in the capacity a theory possesses to predict events then every scientific discovery, every engineering design, every invention is evidence of its truth. Scientific theories must be of a deterministic nature. They have to expose order and logical connexion among scientific facts. They have to stand the test of showing that the order within science enables an order within nature to be brought to light. If there were no order in nature there could be no order in science.

It is easy on this basis to slip into a very fallacious approach to such questions as prediction and determinism. We easily slip to the conclusion that if we knew sufficient about the distribution of mat-

ter in the universe and about the mutual interactions of every particle the future could be laid bare before us. To adopt this viewpoint is to be guilty of something unnatural, unrealistic. Scientific theories and scientific prediction are made by human beings with the material at their disposal, with the knowledge and the scientific instruments that have been gathered and created up to that point. It follows that one of the most realistic assumptions that has to be made in every scientific analysis is what might be called a principle of ignorance. Our powers and knowledge are restricted. Events are occurring that at the moment are outside the scope of our study and any imaginary theory based on the assumption that if we knew everything in space at any given time we would know everything in time within any given space, is a pure fantasy. It is outside physics. It is metaphysical.

This principle of ignorance which is as fundamental to our approach as any principle of knowledge implies not only that events are happening beyond the range of our strongest telescopes but also beyond the range of our most effective microscopes. The field of knowledge is restricted at both ends and science as it develops extends this range as far as human ingenuity and human needs can carry it.

This has a very important bearing on the problem of determinism. It implies that in the field within which science works it would be false to expect that every event that occurs can be fitted without exception into a complete well-rounded, highly-polished set of scientific laws. If this were the case, there could be no such thing as accidents. A realistic science must find a place for accidents. even as it formulates its general laws. This does not mean that the existence of accident implies in some sense the presence of the mysterious. It may be that an individual occurrence cannot at any given moment be linked up with what we have regarded as the ordinary sequence of events, but nevertheless the fact of such an accident itself becomes an expected and to that degree a rational thing—once we clearly appreciate the meaning of our principle of ignorance. Intrusions from outside the restricted field of knowledge are themselves natural events.

To leave it in this position, however, would clearly be unsatis-

factory and scientists have therefore devised methods of handling such peculiarities. Let us illustrate with two cases. Whatever be the detailed history of the origin of the earth occurring as it did at a time outside the range of precise knowledge, whatever be the theories that have been produced to link this event with known laws of development, as far as we are concerned we must accept it in some degree as an accident. Now the detailed mode in which this occurred will clearly have a determining effect on many of the subsequent changes that take place on the earth itself. For example, if the earth was thrown off from the sun its composition will be that peculiar to the region from which it was ejected. So will its initial temperature. There are many factors in such a situation that must be classified together as representing the situation at the actual accidental origin. Given these accidental peculiarities, however, the changes on and within the earth occur systematically, and according to known scientific laws. Out of the initial disorder emerges order, out of accident, regularity. The subsequent history of regular changes on the earth are contingent on the initial accident.

The second line of approach is to recognize certain forms of regularity in groups of accidents. If we take a target, for example, the mark of each shot shows a deviation from the bull's eye which in ordinary speech we explain as being due to "errors" in sighting and in setting. Whatever they are "due" to, they constitute the uncontrollable accidents. They represent intrusions from outside the controlled field of the marksman. And yet, the distribution of shots on a target, provided there are sufficient of them, shows a very characteristic appearance. They follow a certain law—a law of accidents. We shall later return to this question in greater detail.

Scientific laws nevertheless are not simply descriptions of natural processes; they are themselves instruments for action. Historically man's object in pursuing science is to seek control over nature, to make of the world what he wishes, provided it can be so made. Thus that part of nature that is man itself embodies one of the forces that shape the course of events, and science is the instrument that serves him to that end. Is he indeed free in this process, or is he himself a mere mechanical agent, the victim of more fundamental laws that govern and control him as rigidly as the movements of the

piston are guided by the cylinder and the explosion? Does he not plan as if he were free? It is impossible in the space of one chapter to deal with more than one slight aspect of this question.

In the last chapter reference was made to the difficulty some people feel in believing in the possibility of laws of nature that "govern" the actions of human beings. The difficulty is both of an emotional and of an intellectual nature, and arises from a contradiction between a feeling and a set of ideas. We all feel individually that within limits we can do what we wish; while we know, and we feel, that we cannot jump off the earth, we feel and we know that we can walk out of the house in which we are. Or we can stay where we are, just as we wish. *Within limits* we feel we are free agents. On the other hand, if the universe—and by the universe we mean every element of the universe, including our actions—were to follow certain laws of nature inexorably, how could this be reconciled with the freedom in choice of action that we feel we possess? We find ourselves involved in a contradiction, a tug in opposite directions, our subjective feelings pulling one way and our intelligence apparently the other.

From this conflict people tend to range themselves on two sides, each of which again involves a contradiction.

On the one side are those who deny freedom after *liberating* themselves from preconcerned prejudices by intellectual analysis; on the other, those who are *compelled* by their feelings to assert that they are free.

Let us endeavour to think out this problem, to resolve the contradictions we have here exposed. We must first sharpen the contradiction and then proceed to find a background against which both standpoints may be seen and reconciled. As they stand they seem irreconcilable. We shall have to recast our problem in the light of facts.

Certain data we can accept at once. We all have the feeling that we are free to choose. It is a feeling. Can we settle exactly what ideas and precisely what kind of actions correspond to this feeling? Now, the first point that interests us and on which we require information is the qualification that is made *within limits*. What are the limits?

We cannot jump off the earth. We cannot lift a weight of more

than a certain amount, no matter how much we may try. There are physical limits. Sometimes we feel falsely about such a matter. I ask you whether you can run a mile. You feel you can; you try; you fail; you feel you cannot. You have changed your feeling in the practice. You have discovered a physical limitation, and an unfounded feeling.

But, you argue, you still feel free to do all the other things you can do. That also we can accept, but the fact that we sometimes feel free to do things we cannot really do is rather serious. We can have feelings apparently about imaginary possibilities. After all, we follow only one course of behaviour at a time. If we can do only one thing and at the same time in the doing of it we feel free to do that and other things, we begin to have some doubts about trusting to our feelings alone in such matters. Or we may put it even stronger. Let us suppose we were placed in such an awkward situation that there was clearly only one thing we could possibly do, would we say we were compelled to do it, or would we say we were free to do it? If we were bound hand and foot, and wanted to go for a walk, it would be an abuse of language to say we were free, but our bonds would not permit. We certainly would not be free to do what we want. There is, however, such a thing as resigning ourselves, recognizing that we are hopelessly bound hand and foot. If the result of this recognition changes our desire, and we no longer want to go for a walk, but want to remain bound hand and foot, are we not at once free?

The illustration may appear far-fetched, but it contains the kernel of a truth we seem to be approaching. Perhaps we can state more concisely the point we have reached, stating it in the form of a question, so that the original contradictions stand out more sharply: Are we free to do what we must want, or are we free to want what we must do? Which are free, our wants or our actions?

Let us get rid of this awkward undefined word "free" in this connexion and think instead in terms of restraints. When we do so we are finally faced with two problems of a more specific nature that arise from our last query.

How do wants and actions condition each other?

How far does the world outside the individual settle or condition

both his wants and actions? If they are *both* "bound hand and foot" as it were, the matter is settled. Thus the problem is clearly associated with the whole discussion of natural law, and, in particular, natural law for human beings. We have, however, a certain small crop of sweepings for our bag.

First, if there is a meaning to freedom in practice it is freedom only *within limits*. We are definitely restricted by material circumstances. But we seem also to be restricted by our feelings. There are some things we can't do because we say we couldn't bear to do them. Thus our feelings are also suggested as controlling influences on our actions.

Secondly one of the results of recognizing our limitations is a change in our feelings, our desires. He then feels free whose desires coincide with what he can do. Desires in this way become the spur towards action, seeking out the things that can be done.

We are led, therefore, to distinguish between an unfounded sense of freedom and one well-founded in objective fact.

Freedom, it has been asserted in this connexion, is the recognition of necessity. This compact statement requires amplification. A well-founded sense of freedom arises in a situation where, the limitations having been recognized, we are able to bring the desires we have in that situation to final fruition. In exploring the avenues we search for freedom.

If we remind ourselves of what we have said of natural law, however, a great deal of this argument is seen to be boxing with a shadow. We warned ourselves explicitly against thinking of such matters in terms of some outer necessity, a set of eternal and external laws governing every element of the universe. On the contrary we saw that law in nature implies the classification of behaving matter and other natural processes. The form in which it is stated is forced on us by the fact that only in that form can it be used without physical contradiction. We can now appreciate how this view removes a number of the obscurities in the previous discussion. We take a group of shoppers, for example. They are out to exercise their "freewill" in the choice of articles. There are physical limitations to their choices, they are limited in their financial resources, and this restricts them to a certain class of goods. They cannot travel

more than a limited distance from their starting-point in the time at their disposal. This restricts them to a certain group of shops, and so on. Let us suppose these have all been detailed. We now have a selected group of people in specific circumstances about to exercise their freewill.

We propose to be scientific in our study, so after elaborate examination of what they purchase and so on, we presently formulate a statistical law that tells us how people who exercise their freewill in these circumstances behave. We have begun the scientific study of freewill behaviour. As we have already seen, shopkeepers, railway statisticians, and others of that type already know a great deal about just this sort of freewill, and have the laws that "govern" their actions very well established; so much so, that they are prepared to expend vast sums of money on the making of a profit from a knowledge of these laws. In this way is it possible to predict how large numbers of people will act when exercising their freewill.

"This is all very well," it may be argued, "but all you have shown is that the actions of large groups of people can be predicted. This does not affect the fact that as individuals they are still free to choose and act differently. They don't all do exactly the same." This criticism is equivalent to the statement that when you test an ordinary physical law in a particular case it is, in fact, found that there are deviations from the law in that case. There we called them "errors," and as we saw they arose from the interconnexions of the experiment with the rest of the environment. In the case of human beings we do not call them errors, although we do frequently refer to them as *aberrations* from the normal. We may even call them personal idiosyncrasies, and these also may be examined in precisely the same way so that finally we say: "When he exercises his freewill he does so and so." It is just because we can get this consistency in his behaviour that we call him sane.

The position, then, to which we have apparently arrived is that, broadly speaking, the feeling of freewill in the individual is irrelevant, if we are concerned to predict behaviour. This does not mean, however, that we may not examine such laws in greater detail in order to discover exactly what it is that shapes them. When we accept Boyle's Law, relating pressure to volume of a gas, we may

also be interested to discover how it is that the vast multitude of molecules in the gas, flying hither and thither, involve in the mass just this particular law. Now it happens that we know a great deal more about individual human beings than we know about individual molecules, and therefore in a sense we are in a better position to examine the elements that make up the law than in the case of a gas.

What are the characteristics of a human being that differentiate him from a molecule of a gas or from a stone?

First, he is a conscious being, a thinking, sentient thing.

Secondly, and here we are speaking in terms of subjective reactions, he is purposive. He plans and follows an objective. It may not be desirable for certain scientific investigations to introduce the concept of purpose when it can be dealt with in terms of objective behaviour, but to ignore purpose for all studies would be fallacious.

The third point is one that really touches the tender spot in the whole of this discussion—man has a sense of responsibility. It is because many who attach great value to this sense imagine it is being undermined when the validity of the freewill criterion of action is attacked, that they fight this point of view.

The fourth point is that he has values, he sets greater store on certain things, or ideas, or feelings, than on others.

All these imply needs, some more urgent, some less, and it is his purpose to satisfy them. To that end he plans, and acts, and discovers, and fashions the world about him, to meet his desires. In the pursuit of satisfaction he creates the laws of his behaviour, but he does so within restrictions imposed on him by his environment. It is that environment also that has, in its turn, fashioned the stuff of which he is made into a being with these needs—needs that can be satisfied—into a being with these thoughts, with these aspirations, these sympathies, and this sense of responsibility.

We are now in a position to see where the original confusions arise. The purely mechanistic approach proposes the problem roughly in this form:—

"The behaviour of an individual is determined *in toto* by all the material factors in the universe *outside* the individual, and the laws regulating the operation of these factors can be discovered by

ordinary scientific methods in the laboratory."

The protagonists of freewill assert:—

"The individual's actions are directed and controlled by internal factors only; in this he has a free moral choice."

The mechanistic approach does not recognize that the individual, with his capacity for thought and analysis, is himself also one, and a peculiar one, of the causal factors in the situation. He directs a flow of human energy. While the mechanist is correct in asserting that the universe outside the individual restricts and conditions him, he does not admit that these restrictions are also canalizing in their effect. They do indeed place a situation before the individual, but he is not an ordinary inert piece of matter but one endowed with special qualities, a being possessed of consciousness, capable of recognizing the necessities of the situation, and striving to act. In these circumstances this individual brings his specific qualities, his properties, to bear, and it is the interaction of these qualities with the material circumstances that determines the final outcome. The individual therefore has also to be seen as one of the forces in nature, and for their study the social laboratory besides the purely scientific laboratory is necessary. Believers in freewill, on the other hand, under-estimate the conditioning effect of the material forces on the desires, valuations and moral judgment of the individual, and direct attention to a subsidiary element in the situation, viz., a subjective feeling of freedom that accompanies the operation of the human force. Thus the sharp separation between the individual, and his material and social environment leads in both cases to a false antithesis.

There is indeed a distinction which must not be lost sight of; it can best be seen when the relation of all this to the problem of prediction is examined. If a scientist understands the nature of the material he has to deal with, i.e., the necessities of the situation, he can venture on a prediction. He can assert, for example, that an eclipse of the moon will take place at such and such a time. In the sense in which we have talked of matter making its own laws in its behaviour, we can say that the moon will make the prediction come true. The moon nevertheless will not be conscious of its own necessities nor those of the other bodies among which it has to

move. In precisely the same way a human being, conscious of the necessities of a situation in which he finds himself, may venture on a prediction concerning his own behaviour, and will set about making it come true. He will make it come true by planning purposively, and it will actually come true if he understands the necessities of himself and his environment as well as the scientist understands those of the moon. Because he is matter at a higher level of development than the moon, he can be his own scientist and his own material for study. He is at once both scientist and moon. He can become a conscious maker of laws, both individual and social.

Nevertheless this is no easy task. We lightly under-estimate the extent to which the external world moulds and restricts us on all sides.

Man is a creature of the world, a creature of society, a creature of his group, of his immediate environment and of his own make-up. In so far as he becomes conscious of these necessities, understanding their laws of change, acquiring a sense of responsibility through himself to the group and to society, does he become a relatively free man and a conscious force in nature? He becomes free in realizing where and how he is bound and in directing his purpose on that conscious basis. To assert that man is free in some absolute sense is to fly in the face of fact. To realize that he can become more free and to take steps to that end is for man to become a causal agent in fashioning the way to freedom and to the removal of restrictions. He thereby gives a meaning to "human freedom."

To see the problem from this angle is to break down an isolation between man and the material he studies that has traditionally influenced the outlook of the scientist. The cleavage between matter and mind leads—unless we are careful—to the idea of a set of mechanical laws, self-contained and self-subsisting on the one hand and to a set of abstract ideas, logically interconnected on the other. To attempt an explanation of the two in terms of them separately is to strive to bridge an unbridgeable gap. Between the activity of the scientist and the energy movements of the material with which he is concerned there is a qualitative relationship. Each affects the other. Each is a causal agent on the other. Each shows effects, traceable to the other. Between them they grow and develop as a unity.

Once we recognize this the old problem of mind versus matter disappears and in its place emerges a new field of scientific study. It is concerned with the multitude of problems associated with the query: what is the nature of the changes through which this active relationship of mind and matter passes, and in that process through what transformations does the mind and the matter separately pass?

Physical science, however, deals with those aspects of the universe that can be approximately isolated from interference by human beings or from the artificially excluded environment. We have seen that for this reason there must always be present an element of "uncertainty" in scientific prediction. It is on that understanding that we talk of determinism within the framework of science. Without this qualification the meaning of scientific investigation cannot be appraised. Now this uncertainty must not simply be attributed to human ignorance. It is inherent in the whole question of scientific law. A law is a statement of an observed regularity taken at a particular level. The regularity may be a chapter of accidents like the systematic arrangement that shows itself on the target. The law of one target has to be compared with that of another. It tells us next to nothing about the nature of any individual mark. In the light of that law any attempt to specify the latter involves an uncertainty. This does not imply that there is some sense in which the law is not real nor does the law deny that the elements from which it has been drawn are individually to be regarded as accidents. What it does say, however, is that any deduction drawn from the law will involve the concept of probability. We may attempt to predict, for example, where the next mark on the target will appear. We can only do so by specifying a probability to each point on that target. On the other hand, we may predict what the next target will look like after it has been shot at a certain number of times. This also we associate with probability. We make the prediction tentatively and the answer is derived from a study of past targets. When we talk about determinism in science we mean precisely this and those who would interpret it in terms of a system of perfected laws, applicable in a unique form to all levels, to target and to mark-on-target alike, are guilty of a confusion in scientific method. We have to keep clearly before us that every statement describing a group regularity

implicitly shows itself as implying an uncertainty in the elements that compose the group. Order and disorder, accident and regularity, these are the opposite characteristics that are present at every level of scientific study.

Within recent years a "principle of uncertainty" has been proposed in science, involving the assertion that there are certain elements of the material universe, of a sub-atomic character, that because of their fineness in size are beyond the limits of human measurement. We cannot know their movements in detail, nor can we lay down conditions under which all such particles will behave in precisely the same fashion. Their behaviour has to be described in average or statistical fashion and in any particular case can therefore only be specified to a degree of probability.

All this may be true, but it is the conclusions drawn from it by some scientists that particularly interest us. Since no precise data exist on which exact predictions may be based in this case, it is asserted that determinism in science has broken down universally, once and for all, and this view is underlined by the assertion that if the basic elements of which matter is composed are themselves outside the scope of deterministic study then the laws of large scale matter are not "in reality" laws but appearances only, arising from the summation of an enormous number of indeterminate elementary happenings.

Now the first point to note is that the facts from which these conclusions are themselves deduced originate out of a deterministic scientific procedure. Logically the position would thereby be reduced to an absurdity unless we recognize that we are refusing to interpret determinism in the appropriate sense. In the last resort the test of the validity of the scientific method is a practical and a rational one. If it passes that test it reflects the processes in nature whatever be the theories of the constitution of matter. The fact that there does exist a limit of fineness beyond which it is not possible to obtain adequate data to apply the simple deterministic method must be taken as a sign that other aspects of determinism are here important. Far-reaching positive assertions striking at the established foundations of scientific method and reducing it to an irrational procedure must not be made on a false basis. Actually the principle of

uncertainty tells us the precise nature of the predictions that can be made by the deterministic process in circumstances in which the available data are of a more restricted nature than is normally the case. Such predictions naturally become then statements of probability. Curiously enough, while it is not asserted by those who clamour for the inapplicability of determinism to inanimate matter that the atom is in some sense "conscious" or "self-conscious," they have not hesitated to suggest that something akin to freewill reigns within it. To assert this is to carry to absurd lengths the antithesis to which we have already referred—the antithesis between old-fashioned mechanical determinism and freewill—as if where the former is inapplicable, the latter must hold sway.

The lesson we have to draw is that to each level of matter its specific system of laws, and therefore its specific kind of determinism and the scope within which that determinism can be applied in practice is itself settled by the extent of the data from which inferences can be drawn. Unless we will keep this clearly before us we are likely to slip into mysticism where none exists.

CHAPTER NINE

THINKING ABOUT ART AND VALUES

A FRIEND TELLS ME that Beethoven is a much greater musician than Wagner; that Dostoevsky as a writer understood human nature in an incomparably deeper sense than any previous or any later writer; that politics is mostly a nonsensical farrago of prejudice; that next to Shakespeare, Shaw is the world's greatest dramatist; that no wine that has ever been made can compare with good old English ale; and that Britain is the only country in the world where liberty exists.

Are these statements true?

How many times have we not heard and taken part in discussions in which just this sort of talk arises? They may not deal with books, or music, or pictures. Perhaps they may be more frequently concerned with jam or foodstuffs or the quality of cooking generally; with hats, and frocks, ties, suits, and clothing; with the advantages of travelling by road, train, or by air; with football, tennis or golf. The disputants may become "hot and bothered" as the argument gets more and more intense, and usually more and more confused. What was at first a single point of disagreement gradually broadens out until an ocean of differences separates the partners to the argument and a friendship may become imperilled.

Let us examine some of these questions a little more closely so that next time we are involved in such a dispute we may know exactly where and why the differences occur. For contrast let us begin with a different case.

What is the distance round the earth at the equator? I say it is 25,000 miles; who will dare dispute? If you care I can satisfy you in a variety of ways. We can look up a series of books on geography, or on geology, or on astronomy. We can ring up the secretaries of the learned societies associated with each one of these subjects and check my statement. We can follow through in detail a description of the method that has been adopted on many occasions by those who have made it their business to measure this distance; and finally we decide they have "no axe to grind" in pre-

ferring 25,000 miles to any other figure. All sorts of people with different temperaments, different upbringings, at different periods in history have reached the same figure and have reached it either by repeating each other's procedure more carefully or by devising a new method of their own. More than this. By assuming that the circumference of the earth is just this distance, all sorts of other measurements fit in with this. Here, then, is something about which there is no question of disagreement. We say it is an indisputable *fact* about the earth. Sometimes we say it is a *scientific* fact. Those of us who haven't the means, the apparatus, the technique or the intellectual capacity to carry through the measurement for ourselves can act on the assumption that it is a fact. It leads us into no inconsistencies; everything that follows from it works out all right.

Scientists are concerned with indisputable facts. Discussions at scientific gatherings are either about facts, or methods of grouping facts together, i.e., theories. Being human beings, however, they may get "hot and bothered" about the theories, but the facts are not usually in dispute.

It is of no importance, you say, to know the distance around the world. Shaw is reputed to have gone even further than this. When told it was ninety million miles from the sun to the earth, he said he was astounded at the magnitude of the lie! When you assert that it is of no importance, what you are implying is that it is of no importance to *you*. But let us remember that there are people who spend all their lives engrossed in discovering just such facts. Do we say that it is unimportant to them? Surely not. We may be unable to appreciate how people can find such a dull subject so absorbing that they will lose nights of sleep or take infinite trouble with tedious and wearisome calculations, but that is our difficulty, not theirs. That they do find it interesting is as much a fact as that you may find it uninteresting, or that the earth's circumference is twenty-five thousand miles.

These are all facts, but we have to be precise in stating them, or we will rapidly confuse a fact with a *valuation*. In using the expressions *dull* and *tedious* we are evaluating the process personally. When we say "The film *Cavalcade* is a better production or is more worth seeing than, say, *The Gold Rush*, by Chaplin," we are making a

valuation of a similar nature; we are not stating an indisputable fact. We cannot expect universal agreement on a valuation. It is something personal, although in a sense it is not merely personal. Unless some other people agreed with us in our valuations, we would begin to lose a certain necessary sense of security; we would feel that our own particular sense of values was "wrong," that we were becoming queer, peculiar. We might even feel we were losing our sanity. I shall return to this question of what I would call the necessary social anchor essential to us in our valuations, but for the moment I want simply to underline this distinction between values and facts.

A fact is a truth about the world, a statement that in the sense in which we have explained it, every one can check up for himself, something with a universal quality about it, something we can all act upon in the same way as we act on a recognition of the fact that the pavement we walk on is solid. Individually we are either correct or false, right or wrong on a matter of fact. A valuation is an estimate of a fact. Looked at from the personal standpoint it is a crude measure of the degree of interest the fact has for you, the order of importance in which you place it relative to yourself. You are not right or wrong about this as you must be about a fact. A valuation is therefore to some extent a reflection of yourself. When I go to a strange house, one of the first things I do is to move over to the bookcase to see the sort of books that interest the residents. The contents of the bookcase are a reflection to me of their owner's values in that field at any rate. It enables me not only to perceive a fact about them, viz., the kind of valuations they have, but also enables me to have a line on evaluating them—the interest they may have for me.

We can now return to my friend and his various assertions. That Beethoven is a much greater musician than Wagner is certainly not a fact. It is my friend's valuation of what he might call the quality of their music. It happens that I also agree with that estimate, but that does not constitute it a fact. If I act on the assumption that every one else holds the same view I shall soon be disillusioned. I do not agree with his opinion of Dostoevsky, but there is no question about one of us being right and the other wrong. We are each simply

stating something about ourselves, viz., the nature of the appeal that Dostoevsky makes to each of us. I am not particularly interested in the personal soul-searchings in which that writer indulged. My friend is. They do not seem to me important compared with such other matters as might have been handled by a man of his undoubted talent. To my friend they do. In our respective lists of the important things that have to be dealt with, he and I place such items in different orders.

Is this, then, all there is to be said about it? Suppose I am pressed further, as is common in all such discussions. "Why do you think that Beethoven is a much greater musician than Wagner?" I am asked. What am I to answer? Shall I proceed to dig out "reasons" to convince my questioner that I have made a "reasonable" estimate? What kind of an answer is reasonable? What is a reasonable estimate? Let us see.

For our purpose let me contrast the question as it has been posed with the following:—

What is it in Beethoven's music that appeals so much to you? What is there in Wagner's music that you dislike? If we ponder over these two questions we begin to realize that the original question treated the problem as if a preference for Beethoven arose principally out of an intellectual analysis, the latter question as if it arose out of a direct emotional response. An individual would be perfectly entitled to reply: "I like Beethoven and I cannot give you reasons. I just like him." The fact that he could give no reasons would not affect the fact that he liked the music.

We must not confuse an emotional response with an intellectual analysis. Once we realize, however, that we are dealing here with a personal preference, we can accept the query in its original form and proceed to answer it, if we can, by discovering what in our past history and environment moulded us in such a way that Beethoven's music appeals particularly to us. Such an answer would indeed explain why we like Beethoven. At this stage what might have been an argument about the relative merits of two musicians becomes an examination of how the respective disputants come historically to acquire the valuations they have. The parting shot becomes: "I have not acquired the same valuations as you have," instead of: "I do not

agree with the reasons you give."

Very much the same situation arises in connexion with humour. Even if I were to make an intellectual analysis of jokes and decide that it is the element of surprise, or of incongruity, of the ridiculous, of gross exaggeration, or any other characteristic that is responsible for moving me to laughter, I do not move about life with these various categories in my pocket, using them on the appropriate occasions. If I am faced with a remark I do not pull out these "tests" from my pocket, and if the statement passes one of them satisfactorily, decide that this is a joke and deliberately proceed to burst out laughing. My amusement is immediate. When the laughter has subsided I may, if I am interested in analysis, proceed to ask myself which characteristic of jokes, as I have catalogued them, stimulated me on this occasion. Laughter is an emotional not an intellectual response, but the analysis after the response is intellectual.

What I have said here about music and humour applies with equal force to other artistic forms. A picture is placed in front of us. We either like it or we don't. Whatever the result, no reasons need be given. How often have we seen this process reversed in picture galleries. The critics have told us that this or that painting is superb. Streams of people move steadily past the paintings, catalogues in hand, making up their *minds* that they ought to appreciate the proper pictures. If preparation were indeed needed it ought to be not intellectual but emotional preparation, acquiring the mood to respond to something that must appeal primarily to the senses, if we can respond at all.

Now let me say at once that I do not want to convey the impression that the intellect plays no part in these matters. On the contrary the mind and other human characteristics are very profoundly concerned. A single illustration will suffice. I hand a sheet of paper to a colleague.

"How do you like that?" I ask.

He examines it carefully and for a few minutes his brows pucker in intense thought.

"It's beautiful," he says, handing it back. "The way the argument is developed is magnificent; and how surprisingly simple the result turns out to be."

It is a highly technical piece of mathematical reasoning. I hand it now to a chemist, a biologist, a philosopher, a linguist, an engineer, a joiner, a bricklayer, an artist or a politician. They gaze at the paper blankly. There is no emotional appreciation of its beauty because it *means* nothing to them. Its *content* is lost on them and its content was essentially intellectual. It had no beauty for them because they lacked the particular experience that would enable them to appreciate where the beauty lay. They could not possibly react to the exquisite adaptation of mathematical form to logical conclusion that it exhibited. It is precisely as if I had shown them a poem in a foreign language.

But intellectual experience is not the only source from which æsthetic pleasure may emerge. Pay a visit to any well equipped museum and examine the exquisite ironwork in the form of gates and railings of the fifteenth, sixteenth and seventeenth centuries that were produced to adorn entrances, windows, and surrounds—marvels of craftsmanship. How much of the æsthetic beauty do we miss who are unpractised in the making of such things? How much more is patent to the eye of a master!

A work of art, something that has value for one, must therefore be understood if it is to be appreciated, but it is understanding in a wider sense than mere mental understanding, merely knowing how or why it was constructed, but the kind of understanding that arises from the fact that it deals with one's own experience.

An individual who has spent his life in the enjoyment of fox-hunting, may prize very highly a picture that brings to him again the exhilaration of the chase, but such a picture would have little meaning and therefore be little valued by a town dweller who had spent his life in a factory. A worker experienced in the joy of controlling and guiding a large machine might treasure a sketch that evoked in him anew that sense of power over matter. To him it would be a work of art that would leave the fox-hunter completely unmoved. In each case the picture makes contact with an aspect of human experience, and without that experience there would be nothing from which to evoke the emotional response to which we have referred. Any distinctive experience may therefore be the subject matter, the content of a piece of creative work; a piece of

mathematics, life as a domestic servant, an unemployed man, a political meeting, a revivalist gathering, a day at the races, manœuvring a yacht, clocking-in, pay day, throwing darts in an inn.

I have chosen these illustrations designedly. There is an impression abroad that to be cultured is to be able to appreciate "good" art and that the power to discern its goodness can be acquired, if at all, only after much learning. It is true that to appreciate art at all one requires to be emotionally sensitive, a characteristic depending to a large extent, although not entirely, on one's physiological make-up. But the fact that large sections of the population, particularly the poorer sections, frequently show little "taste" for art, must not be misunderstood. If the content of art has to correspond to deep human experience, several questions arise that must first be answered. Thus:

1. Who have been the artists of the past who were capable of portraying the experiences that would be vivid and real to these poorer people?
2. How many have actually produced such work?
3. If artists had produced such work would they have found it possible to survive? Who would have purchased their work?

When we come to examine such questions we begin to get a glimmering of the extent to which pictorial and other forms of cultural expression of a population are associated with the class of purchasers of art products, and are canalized by the class of art consumers who can pay for art. Thus that section of the population that cannot afford to remunerate such artists as might express their experience in art form, are compelled to satisfy their æsthetic senses at second-hand and by second-rate means. The result is something tawdry and sentimental, a cheap imitation of the art of another class.

To say this, is not to assert that all artistic expression appeals truly only to a class. Whatever the reason for its production, whatever the class that has in the past found it advantageous or pleasurable to stimulate artistic production, the fact remains that much of it appeals to experiences and to emotions that are more or less common to wide sections of humanity. Musicians like Beethoven, Bach, Mozart, Chopin, Brahms, and many others are appreciated and have been enjoyed by practically all classes, nations and races, in Western Europe at least. The same is true of architectural modes, common

as they are to all European cities. We note in passing that Asia and Africa are different; they have produced their own characteristic forms. It is rare to find a European who can derive pleasure from Persian music or enter into the spirit of Chinese drawings.

Ths history of changing architecture in Europe can be seen to proceed step by step with the social development of that continent; the early feudal days of the barons and their castles, the central bulwark for the social unit, then later the manor house with its feudal lord, the ecclesiastical buildings of the medieval period, the monasteries and cathedrals at the time when the Church was the central power over life and death, stronger than kings in the community; the mercantile period towards the end of the Middle Ages, with its merchant princes and its magnificent palaces such as those lining the canals of Venice; the development of cities towards the beginning of the industrial era leading to the typical street architecture; and later the industrial towns, roads to meet the growing transport, factories, and large shopping centres. Thus step by step architectural development has adjusted itself to and found the distinctive form for each social era.

We can see in this way that at each historical epoch a typical form of architecture has been evolved, whose purpose it has been to embody the spirit and to stand as a sign of the power of the dominant section in the community at that period; and the great mass of the population living and developing in that society have unconsciously acquired its atmosphere, and in a certain sense also its valuations. They have watched and taken part in ceremonial in its cathedrals, and, bred and attuned to its atmosphere, have performed their public devotions as a social custom and a public duty. The towering pillars, the arch, and the rising vault have symbolized a power greater than they themselves could individually achieve, a social force, something to worship and revere, something before which their spirit must prostrate itself. So also the towering ramparts of the baronial castle was to the serf in one way the symbol of security, the social focus, whatever else it may have meant for him in dues and feudal service. And in the sense that it did in fact correspond to a need, and seem to him to satisfy that need, and in the sense that the very structure of the building breathed that security, to him it must be

regarded as an object of art, an æsthetic stimulus.

Let us not, however, confuse the æsthetic reactions of the dominated class, the medieval worshippers in the cathedral, or the feudal serf wandering under the protective walls of the castle with the æsthetic feeling of the dominant class itself on whose power these buildings set the seal. If the castle meant security for the serf it also meant thraldom and inferiority to him. To the baron on the other hand it was the material embodiment of his personal superiority and the power of his class, his peers, and equals. To baron and serf the turrets of the castle must have been a source of æsthetic emotion, but each in his turn must needs interpret it in terms of their real experiences of life, and the valuations of their class. In this sense therefore is art social; an outward form to represent or embody a powerful feature, a symbol to arouse an æsthetic feeling that wells up in the onlooker from a social source.

So when I say that many artistic forms must be seen as emanating from a social class, I am not suggesting that these forms appeal only to the class from which they have emerged. What I am trying to show is that by the same form, by the same artistic expression, by the same work of art, two different æsthetic reactions may be stimulated. A class that historically has never found the opportunity of expressing its experiences and its interpretation of life in artistic form, will interpret the artistic forms of another class in its own way.

We appear to have travelled a long way from our starting-point, the distinction between a fact and a valuation, but in doing so we have seen also how the pathway has forked just at a crucial point. The pursuit of fact would lead us to the world of science, the study of values to the world of art. Art in this way showed itself as the concrete form in which the values man places on facts are represented, and if we are to judge from the illustrations cited, the facts that seem to demand interpretation in this way appear to be facts that have meaning for a group; they are in fact, social facts. Even when the subject matter is a piece of mathematical reasoning, as we have seen, it needs must mean something to a selected group that share a common experience.

Is there then nothing in art that is individual? Surely. For just as a person is both a member of a community with the habits, the

dress, and customs, the interests and amusements of his period, so also is he an individual with his own private thoughts, his personal experience that differentiates him from every one else; his special set of likes and dislikes, his individual group of interests and enthusiasms, and indeed his own particular physical as well as psychological make-up. For although we all have much in common, we are no two of us alike. We are the same and yet we are different. We appear to do the same things and we do them in different ways.

Take writers for example. Each has his individual style, his own characteristic mode of expressing himself, his own method of analysing a situation, his personal flow of feeling and his own peculiarities in communicating it to others, or hiding it from others. Watch your friends, and their capacity for describing an incident with colour and vivacity, the extent to which they make it real or vivid. Each in his own way is an artist. He may be a good or a bad artist; he may be master of a technique. It may be effective or ineffective, or he may not even be conscious of the technique. Watch which points he stresses, and which he dismisses in a word, those he places in the high lights and those in the shadows. Above all, note how his mode of description alters as the subject matter alters, how the form of presentation is adjusted to what is contained in it.

He is an artist who succeeds in arousing in you the thoughts, feelings, and actions appropriate to the contents of his story. He calls up mental images, he creates the atmosphere of feeling with which these images have to be associated, and he arouses in you the desire and the energy to do what he considers is the appropriate action. He is a conscious artist who is aware of his own purpose and deliberately devises the technique of expression, of light and shade, of sequence of ideas, to create this effect.

In short an artist is one who can successfully adapt form to content.

Read for example how the writer in the Old Testament creates the appropriate atmosphere in the story of Ruth and Naomi:—

"And Ruth said:

Entreat me not to leave thee, | or to return from following after thee: | for whither thou goest, I will go; | and where thou lodgest, I will lodge: | thy people shall be my people, | and thy God my God:

Where thou diest, will I die, | and there will I be buried: | the Lord do so to me, and more also, | if aught but death part thee and me."

The words are simple and homely. The flow is even and melodious as becomes the subject-matter, and yet the very evenness of the flow and the restraint of the language suggests the depth of the feeling it is intended to express. There is not a superfluous word nor a jarring note; the mood of the story breathes through the language.

What we have suggested about the spoken word regarding the interplay between form and content, and the struggle we continually wage to adapt the one to the other, to put our thoughts into words, and to clothe our words with meaning applies with equal force to all other forms of art; to poetry, to the novel, and to prose generally, to painting in oils and in water colour, to sculpture, and as we have seen, to architecture.

A creative artist is an experimenter. He is continually seeking new combinations of colours, new modes of expression, new combinations of harmonies, new forms of light and shade, new methods of introducing discords to emphasize more clearly the harmonies that lie there. He does not, as a scientist might, squeeze himself out of the picture and merely work out all the possible combinations. He identifies himself with it, sensing, feeling, and testing the new varieties to ascertain if they express what he feels is pent up within him, what he feels he contains. He spends himself. The content is given; it is contained in the social life of the people among whom he lives and in the world about him, and it seeks expression through him. As an artist he does not directly experiment with that. If that content is not given to him, if he cannot experience it, he cannot be an artist. His first duty is to interpret life as it is.

But it would not be true to say that the artist need only be an interpreter. That would indeed put him on a level with the traditional philosopher who conceives it his business to tell us simply what the world means, and not to show us what might be done with it. If the artist is to interpret the world in this other sense, in the sense in which it is real to the members of the community who have to make his art their own, he has to interpret hopes, desires, and ideals, for these are real human characteristics. He has to under-

stand sufficient about the world to be a prophet, a true prophet, in that he has to interpret what such people can do with the world to create the life to which they aspire. He has in fact to be an artistic scientist. He has to be capable of analysing both individuals and society that he may picture a possible and an attainable world. His is no easy task, for this touches only the possible content of his work. His next stage is to discover the form, the medium in which to express this; not simply to delineate it statically, but to express it in the active sense that is desired by those who may feel urged to create the new world. This is the modern mood in art as it is in science and indeed in almost every other form of human activity. Are we not all asking the same question:—

"What can we do in our particular field to help rescue mankind from the dangers that beset it? For what must we strive and how must we do so?"

These indeed are questions, if not already on the threshold of our lips, ever lying at least in the background of our thoughts. The artist if he is to interpret life as it is, if he is to be conscious of the social background from which he has emerged, if he is to be conscious of the part that art has always played in social life, must assist in resolving this great problem. To be unconscious of this, is to be ignorant of the great task of the creative artist at this epoch in history. In this sense his situation is similar to that of the scientist, the politician, and the teacher.

It is in the effort to discover the appropriate form for this task that the creative artist becomes the experimenter, but to experiment without the analysis, before a full realization has been acquired of the content of what he has to express, before the artist is himself suffused with the feeling and soaked in the emotion of the problem, is to seek a form without content. Such art can only be devoid of meaning.

Once we appreciate this aspect of the question a new light begins to be shed on some of our moderns. Aldous Huxley, aware of the decadence of the present but with no hope for the future of mankind, concentrates his writings on the futilities about him. *Brave New World*, a fantastic novel depicting an unsociological state of affairs into which mankind could not slide, where scientists have achieved a biological control over humanity, and converted the

world into a mechanized state of men and machines, can be taken only as an indication that science is an ever-present danger. Had he been conscious that, as the instrument of art, science might assist him to predict the nature of the changes in the social order which man can achieve, he would not have erected this fantastic warning out of his imaginative brain. It is not that we are in danger of suffering from too much science, but from too little. Thus what is used is largely applied to anti-social ends.

D. H. Lawrence, imbued by an intense dislike of a system that destroys men, incapable of analysing the sociology of the problem that arouses his ire, and yet a master craftsman in the handling of form, seeks to escape from the confusion by longing for a new beginning with mankind in some remote corner of the earth; or discovers that the driving power lies not outside among men and women but within men and women themselves, the urge to sex expression.

Modern artists experimenting with form unrelated to anything but the most abstract and therefore attenuated and unconvincing feelings, produce pictures of lines and triangles like jig-saw puzzles, deliberately pursuing form without content, emptying the baby out with the bath. And so we have our cubism and vorticism and a multitude of "isms." That simplicity can be much more powerful in expression than complexity is certainly true, witness the quotation given above from Ruth and Naomi, but simplicity at the expense of content is the denial of art. And all this may be seen as part of the great flight from reality that this last twenty years has witnessed. To be understood it has to be set side by side with the pronouncements of those scientific men who assure us that the colourful world of mankind is in reality but a vast geometrical proposition, devoid of all but mathematical meaning.

There are artists who claim that in the pursuit of abstract art they are stripping it of the undesirable elements in modern decadent society that have degraded it to the "photographic" level, and replacing it by something more permanent and durable. History alone can decide finally the truth in this contention. What cannot be gainsaid is that in so far as highly abstract art appeals only to a very select class of æsthetes, excessively small in number, and does not

fit its artistic forms to express, strengthen and purify, here and now, the creative desires and aspirations of submerged and therefore artistically mute humanity, it divorces itself significantly from the present phase of man's struggle for physical, intellectual and æsthetic emancipation.

But surely, we are entitled to argue, there are many works of art of high merit, and recognized as such by all of us, that cannot be dismissed on such a basis. What of the landscapes of Turner, the paintings of Rembrandt, or of Van Gogh? By what stretch of imagination can these be justly seen as emerging from a social background? What of Beethoven, Bach and Mozart? In what sense is their work related to the social structure, and if they are not, are their individual creations therefore to be condemned? Is there no art that rises above such considerations, elements that have something approaching a universal validity? Are we to say that five hundred years hence these great masters of music will have been forgotten? To refuse to answer such questions would be to flee from the problem we have set ourselves. More than this. To deny that there are works of art of this nature that are likely to live as long as men breathe and sense and enjoy would be to deny what seems almost self-evident.

Mankind has been cradled in an environment we call the physical world, turning himself to the task of mastering that environment for his advantage. In such a situation there are at least three elements:

(*a*) The material and physical world . . . the extra-human environment.

(*b*) The society, the human environment that mankind creates in his effort to erect a satisfactory home for himself in the physical world, including its institutions, its philosophies, arts and sciences.

(*c*) Man, the human being, the biological entity that occupies a place among the animals.

There we have the three primary factors in the human problem. Material from any one of these three may be the subject-matter of the artist, that is to say, it may be the topic whose significance he proposes to communicate to us. His treatment as we have seen will depend on himself, the environment from which he has sprung, and the field from which his topic is selected. There is yet another point

however. The artist may propose to communicate a meaning to us but whether his subject does in fact have for us the meaning he intended is another matter; for all men and women are not alike in make-up or in their experience. The Baronial Castle as a work of art signified to the serf something utterly different from that for the baron himself.

An artist like Turner chooses a landscape, a part of the world not yet appreciably affected by the inroads man makes on nature. His subject matter lasts. It is in an approximate sense, universal. In varying degrees to all human beings nature has a direct æsthetic appeal, and the artist has put his finger on a sensitive spot in the relationship between man and nature. As long as that relationship persists as an emotional reality it will be possible for an artist to succeed with such a topic. On the walls of his cave, primitive man painted pictures of wild animals breathing vigour and action. They were a part of nature to which we are still sensitive; they are works of art, but they are also sociological studies, in that they cast some light on the immediate forces with which he had to contend in these early days of struggle.

Novelists and poets have turned to the interplay of human emotion and feeling, love and hate, sex and marriage, ambition, joy and exaltation, liberty and slavery, peace and strife. In a sense again these are permanent features of the human species, but their import varies from one social epoch to another. They are transient. The love sonnets of one period, sweet as is their musical form, in content lose their cogency in a more sophisticated age. Romantic courtship fades from the social screen to be replaced by the newer realities. The class that found expression in love sonnets passes away, and the central theme changes.

A modern artist chooses as his topic an industrial town at dusk; black factories, gaunt cranes and elongated chimneys piercing the clouds and streaking the heavens in belching columns of smoke; a dull, drab picture in black and white outlined against a darkening sky. We who know it find in it an æsthetic appeal. It is a sociological study, the new struggle of man with man-made industrialism, and man with nature. To the peasant it also means something, something ugly, a demon that may destroy the countryside, an insidious, all-

powerful devil. To the factory worker it is his life, his home, his world. He hates it and he loves it. He has seen it just like that, from the streets and from the outskirts of the town. It broods over him and he over it. Can he master it or will it master him?

Such a topic deals, after all, with an experiment on mankind, and the problems it arouses are of universal significance. The setting is transient, a thousand years hence it may be a record of ancient instead of contemporary history, but the picture will still signify the perpetual struggle of mankind with nature. Only those who have partaken in that modern struggle will be able, however, to sense it in the way a worker now does.

Form in art is deeper than mere outward shape. A landscape, a factory, require to be recognized as such, at least, in order to achieve their artistic purpose. The form is inevitably associated with something material, something perceived by the eye. Can there be a form of art in which this intellectual and visual element is reduced to vanishing point? Can the sense be directly appealed to by a form that is neither visual nor intellectual?

Music appeals to the emotions directly. It has no physical shape in the accepted sense, and its intellectual appeal is not direct. Human beings are biologically entities. They are similar as regards the stimuli that stir them although they differ enormously in their capacity for response, that is, some are more sensitive than others. Music is a pattern of sounds that, entering through the ear like speech, does not focus the mind to objects or ideas but proceeds direct to the emotions. It is to the pattern that the human being responds. It may throw the mind and the feelings back to past experiences, perhaps not consciously. Emerging from it he may find he has re-lived, re-enjoyed and re-suffered the memories of himself, his family, his class, and his race; in that sense it is a new experience to be itself re-lived on some future occasion. Now the significant thing about music is that it may be enjoyed by human beings *en masse* or by an individual alone, but the response to the same musical work varies enormously from person to person. One of the joys of the aftermath of a concert is to realize that one has captured a theme or a portion of the music, and that henceforth it is one's own. In this sense successful music appeals to an aspect of mankind

that is common to humanity, something as it were biological, and therefore also individual, something approximately permanent in man. It is in this sense also that a Bach, a Beethoven or a Mozart appear to stand outside time and space.

To say this is not to assert that there cannot be music of value that emerges particularly from a temporal social context. This as we have seen is true of art in general, but we have to distinguish between art that is well-grounded in the social and biological make-up of man, and so-called art that is a passing fashion, a temporary stimulus to jaded workers, or to a leisured class suffering from boredom. Like popular songs, such art is to be seen mainly as mere muscular exercise.

Form in art is something deeper than mere outward shape. When the artist deals with material things, must shape then not be preserved?

If a caricature be defined as a picture or description of a situation in which some characteristic is especially exaggerated, then all description and all pictures are caricatures. Even a photograph can concentrate only on the outward form and a particular expression. Every writer and every artist in the actual process of creating his work is absorbed in the need to bring out (and therefore to exaggerate at the expense of the others) certain characteristics that seem to him important. That artist is successful who deliberately contrives to make patent what we suspected lurked in the background, to drag to the stream of feeling and the light of mind an aspect that is deemed important to him, and becomes thereby important to us. Thus the purpose of the artist is to make his material as lifelike as possible, but it is "lifelike" in no geometrical sense. A caricature of a leading politician may be more cogent, more emotionally apt and satisfying than any portrait by the foremost painter of the day. For many purposes the electorate on polling day may be more adequately depicted as a flock of sheep than as a set of intelligent men and women. True outward form, meaning thereby true geometrical form, may indeed be useless and misleading.

Science in one sense is concerned with a "copy" of nature, art with the meaning nature has for man. Thus as scientist, man uses his senses for the purpose of noting facts and collecting them together

into a logical system that we may be the better equipped to face the material world and control it. The artist begins where the scientist leaves off. What is my purpose, he asks? Which facts are important for that end?—and importance to him is primarily emotional appeal. He discriminates by feeling, by sensing, and not alone by thought. Thus to the scientist, the artist is a caricaturist of nature; he distorts the form of things in order to arouse in the onlooker his sense of significance. To the artist, on the other hand, the scientist is a caricaturist; he maintains the form of things, he fits all detail mechanically into its allotted place irrespective of their value. The purposes of the two are different. Each uses the world about him to achieve his end, the one to understand intellectually, the other emotionally. All things are parts of the world. All things have significance for us. We need both.

We of this epoch have grown up during the dying phase of a period of intense individualism. As we can see in other sections of this book, we find ourselves naturally approaching every issue with the query on our lips: "How does it affect me?" I am not trying to suggest that there is anything objectionable, or nasty, or morally depraved, about this, for what I have said applies with equal force to those unselfish members of the community who say: "I cannot bear to see such suffering." I am not trying to draw a moral distinction between these two approaches, but rather to underline the sense in which they are the same standpoint. Both begin with the assumption that the world revolves around "me," that it is "I" who occupy the centre of the stage, and that "I" have to decide what "I" should or should not do. "I" am an individual, and it is "my" conscience that tells me whether this is right or wrong. Other people are like "me," and all the other "I's" combine with "me" to form the community. "My" view of the world is such and such, and "I" propose to do this or that with "my" life.

Regarded from this standpoint, "I" look at the world out there and "I" interpret it to "my" satisfaction. If you do not agree with "me" you are wrong.

Now a large part of the earlier section of this chapter was devoted to showing precisely how individual were the valuations we placed on the world. We have been busy bustling ourselves off the centre

of the stage, just as Copernicus unseated the earth from the centre of the universe where early man had placed it, and just as Darwin threw man back among the audience of animals from his self-appointed perch before the footlights. Where science has been able to offer precise knowledge on such matters, the inflated bubble of our self-conceit has invariably been pricked, and our individualistic outlook undermined. We project our feelings that we are unique and distinctive with all their subjective strength into the world about us, forgetting that human beings are all ninety-nine per cent alike. We fail to realize that just as we are frequently unable to distinguish one Chinese from another, so he cannot tell which of us are even Englishmen, German or American. We exaggerate our differences, play out our unique role, sublimely unconscious of the fact that others are playing practically identical parts.

Now all this has been greatly intensified in comparatively recent times, particularly since the dawn of the nineteenth century and the rise of individualism. That period produced its own special brand of philosophy in the attempt to justify the features of the economic period. Members of the community vied in competition with each other for economic supremacy; "Nature red in tooth and claw" became elevated to a principle of action for human beings, and he waxed fat who possessed the characteristics of greatest advantage in the struggle for success. The common humanity of man sank low into the background, and the differences showed up as of prime significance. Freedom, yes, freedom as an abstraction was worth striving for, but freedom for the individual it must be in practice, freedom to pit advantage against disadvantage, force against weakness. Anything else was "unnatural." Salvation became individual salvation and moral precepts demanding the development of individual character penetrated into educational practice. He was valued, he was extolled who was possessed of outstanding characteristics.

And so art acquired the same complexion, the novel with its hero, the theatre with its star, the paintings of fat aldermen and grubby men of money. Individualism had penetrated deep into the thoughts and values of men when its very art served to express this principle. History, too, reflected this mood. It became the story of kings and queens and wise counsellors against whose great deeds and

outstanding virtues the social life of the people was of little consequence. Now while the economic structure of the individualistic stage is at last crumbling before our eyes, the values we have unconsciously acquired and incorporated into our institutions of learning and of art still remain with us. They are reflected in our whole outlook and in our standards of criticism. A film depicting a great engineering feat such as the laying of a railway from Turkestan to Siberia, that might completely transform the culture and the populations of a vast area of the globe, is "dull" in contrast with a film featuring one of our latest stars. That there must be a focus of interest is admitted, but in demanding that the centre be held by an individual with whose doings we also as individuals can identify ourselves as we sit tamely by, we are applying an artistic criterion that has its origin in an already dying epoch of society.

But change is upon us. An eye cast over the agonized face of the West easily sees that within a short historical period man will have fought his way to a new social level, in which the common elements in mankind, the enduring elements in us, will be the binding factors, and individuals will find their place not as disruptive units each fighting for the centre of the stage, but as natural elements in a common enterprise. If this is indeed so then new values will be born, criteria of good and of bad art will swing from their present individualistic trend to others more securely founded in social order and conscious social activity, prizing action in common above the erotic exploits of a modern Apollo or the love play of a Hollywood doll.

CHAPTER TEN

THINKING ABOUT POLITICAL PRINCIPLES

POLITICS ARE concerned with problems of government. Their importance rests on the fact that if the decisions arrived at are incorporated into law, they affect the lives of us all. For not only do they regulate and circumscribe our conduct in innumerable small ways, but large masses of the population may have their station in life and the future bodily and mental health of their children determined for them by the legislation that is passed, and enforced in the last resort by the police, the army, the navy, and the air force, the so-called forces of law and order. During a national crisis, a war for example, our very lives rest in the hands of the government in power. Moreover if a moment arrives when political action is called for, and there is no true understanding of the real meaning of the situation, the consequences that ensue to us all may take generations to overcome.

Those who would argue, therefore, that politics is a futile game for over-enthusiastic youth, dishonest place-hunters, a cesspool of prejudice, and a source of intrigue, outside the realm of intelligence or honesty, can be counted out as having lost interest in what may most vitally affect them. Alternatively, of course, they may have decided after elaborate study that history pursues its course undeflected by the political contortions either of the electorate or of party leaders, that governments come and go, each performing automatically the task its rival would have performed had it been in its place, mechanically delivering the speeches and going through the gestures of arriving at decisions already settled for it; that when a government of one complexion ventures on legislation of its own, at the first opportunity its rival hastens to repeal its laws, and so sets history back on its predestined course.

Such a view, attractive as it might appear to those already well matured in political cynicism, is not easy to maintain *in toto* by any one who has had his desires frustrated and his activities curtailed by the relentless demands of the tax collector. It might nevertheless be

argued with some show of reason that the political views of the electorate are themselves of little consequence in deciding these matters; that not only are people not equipped intellectually to arrive at decisions on matters of State policy, but that they cannot have the requisite information at their disposal to enable them to exercise their judgment even if they were possessed of that quality, and that in any case their minds, their views, their emotions, their desires, and their actions are settled for them by politician, pulpit and Press.

On this view the political outlook of the electorate is not a prime cause of change, but is itself mainly settled by factors of a much deeper character. In evaluating this thesis, therefore, we are being thrown back on a problem of a much wider scope; and legitimately so. For if our social, industrial and political history ought to be directed by the desires of the peoples affected, is it not vital to understand what it is that determines these desires? Unless we can become aware of these forces, and in so doing if possible rise above them to a new level of understanding of ourselves and our environment, how can we be anything but the unconscious marionettes that answer to every pull of the string, believing in the free exercise of our judgment at the ballot box as an automatic machine might believe, if it could think, that it chose of its own freewill to render up its quota of chocolate in return for the proffered coin?

It appears, therefore, that we shall have to discuss with some care this whole question of how our judgment is unwittingly affected by matters outside our immediate consciousness; but that is not all. Yet another problem that interlocks intimately with this has already been touched on. Is it possible to analyse the principal factors that settle the social, industrial and political development of any country, and to discover how far these include the political views of the electorate at all? Is our political cynic, perhaps, right after all when he asserts that history is a sort of fatalistic process that rolls along its predestined path irrespective of what you and I may say or do; that we are indeed mere puppets of history, waving our arms and speaking our parts not perhaps at the will of single individuals but at the dictates of superior economic forces?

Let us make it concrete. Was the war of 1914–18 the inevitable

climax to a previously existing situation, the shot at Sarajevo a trivial incident of no consequence because the war was already upon us after premonitory rumblings that dated back many years? Was the cry, "Rally to the support of plucky little Belgium," the cry of a marionette, and we who rushed to save civilization[*sic*], automatic machines responding to the pull of a lever? Can we look back with equanimity and say now that our feelings and our actions then were based on an informed judgment and an adequate understanding of the issues? Was the war fought because we believed a moral injustice was being meted out to Belgium, or was that case manufactured for us after events had shaped their course? Could our moral judgments be legitimately ranked with the *causes* or with the *effects*? Do we in fact justify our actions after the latter have become unavoidable necessities? After all, no one in history has ever fought to maintain what he conceived to be an unjust cause. In every war both sides hold they are fighting for right, and almost without exception they receive the blessings of the custodians of public morals in that struggle. German and British church leaders alike pray for the victory of the arms of their respective countries. Even Hitler and his Nazi Party "justify" their aggressions on the score that Germany has been unfairly treated.

Is it possible that the underlying causes of the war of 1914-18 were still present during the making of the Treaty of Versailles and that the long period of post-war distress, anxiety, tension and finally rearmament were simply the working out again of these self-same underlying causes? Is it possible that the coming of Hitler and his party, with all its oppression, brutality and ill-treatment of inoffensive minorities was an almost inevitable consequence of that same situation, and finally is it not more than probable that the present outbreak of war again is nothing more than a repetition of the 1914-18 struggle once more brought to a head, in a more intense international situation, by the same underlying causes?

Now it should be noticed that all these questions are being directed towards the same objective. We are in reality inquiring to what extent there is a species of causality, to what extent there exist overriding laws of cause and effect, in large scale social affairs as distinguished from the more detailed problems we have hitherto

considered. If there are, we are naturally interested to know whether our experts in these matters, viz., our politicians, have discovered and work on an understanding of these laws. For notice, if the kind of causality here suggested does in fact exist, a peculiar light would be thrown on the high-sounding policies and promises that have from time to time been voiced by leading politicians in their platform speeches. Again and yet again we have been offered remedies for this or that social evil—"prosperity is round the corner," "wise and understanding statesmanship has led us out of the slump," and life will presently be its old humdrum self. The implication in each case is that the power to handle these issues successfully, rests entirely in the hands of the government concerned. If there are indeed forces of an international character at work that exercise a decisive effect on the internal arrangements of any one country, then the speeches of these politicians make painful reading; for they would imply that the very individuals into whose hands the control of our destinies has been placed have not yet begun to understand the forces at play. What would we think of an engineer whom we had called in to deal with some mechanical defect, and who turned out to be ignorant not only of the principles of mechanics but of the fact that there was such a subject as mechanics? Even if in the past he had succeeded, by tinkering about with a piece of machinery, to get it to run for a time, would he not be completely at sea when faced with a serious breakdown? Is it the case that our outlook on these political issues is still of the tinkering sort that does not even know how to begin to ask sensible questions about the issues that meet us at every turn?

Clearly we have to rid ourselves of many illusions. We have to think of politics and all that is involved in it, scientifically, objectively at first, on a wider scale than the mere detailed problems presented to us at elections. We have to see politics as one of the ways in which history is being made. If there are political principles, just as there are mechanical principles, then we have to see government as the practice of these principles, society as the laboratory and we, mankind, as the material upon which the experiment is conducted. Then we have to become conscious of the fact that by our actions we make history, and seek methods of controlling that experiment

consciously and deliberately.

There is one trap into which most of us easily fall. We have stressed the need for distinguishing a fact and a judgment. Now in political matters we are constantly liable to this confusion. We get sidetracked from an analysis of how a certain situation has arisen and turn to condemn the motives of those who have brought that situation into being. There are studies for which motives may be almost irrelevant. We are not usually terribly interested in the good motives of our friends who get us into trouble. It is more important to know how it all happened and how to repair the damage. We ask, what made them do it. Equally we are amused when someone with a bad motive does us a good turn. It is not so much the stupid intentions people have, that matter, but their actions. It is surely a short step from this for us to recognize that our moral indignation may be a secondary matter if we are to understand how a situation came to pass.

This is not to assert that human beings do not act " of set purpose," with good or bad intentions, but rather that these intentions may not be the primary causes. They may be the "justifications" for actions dictated by other forces of which they are not fully aware. With a friend I discussed the invasion of Poland by German troops. "I wonder why the German Government found it necessary to do that?" I ask. "An act of pure aggression," my friend replies. "You would surely not attempt to justify that?" and the discussion comes to a dead end. He is more concerned with a moral estimate of the action than an understanding and what in fact were the necessities.

"Why does Germany," I ask, "continually put forward this demand for colonies and for empire?"

"Pure jealousy, desire for power, prestige . . ." comes the answer. In this way we are headed off from an examination of why industrial countries like Britain, France and Germany seek colonies and empire, by saying it is some form of wickedness on the part of a country that came later on the field. Of course, if it is wickedness, the only solution is to beat the devil out of the wicked. But suppose they cannot help themselves—what then? Supposing modern Germany is treading the same path as Britain and France trod in the

seventeenth and eighteenth centuries. No one would assert that the present British and French Empires were deliberately designed by some group of schemers, two centuries ago. But neither was it a miracle. It was a perfectly understandable development that followed from the industrial and commercial needs of the home countries. As it occurred no doubt each step was given its justification, and those who carried it through probably believed they were performing a necessary task of civilization. What is important to ask is why countries with an industrial structure like those of Britain, France and Germany either actually acquire colonies and empire by conquest from the inhabitants, or fight each other for that purpose. After all, Britain drove the French out of India and Canada; no doubt both contended that right was on their side. Every country fights in its judgment not only for its own rights but for those that transcend its immediate interests—for the good of mankind. Generations after this mankind may be in a position to judge—and perhaps to smile cynically.

If we can grasp this idea we can be freed from the confusions and stupidities of blind political proposals, for once the analysis is developed we should be at last in a position to examine any given proposal as a concrete contribution to the solution of what is, in a certain sense, a scientific problem, the affair of every man. We should be able to see it as a bit of history, a proposed experiment, and judge it as one would any other experiment in science, by what the experimenter hopes to achieve by it and by the evidence that this hope is at all justified.

History is made by human beings. We—you and I—make history. There are no subtle mysterious agencies at work beyond the wit of man to understand; here, as in other branches of science, we begin with this assertion. When we talk of economic forces we mean actions by individuals and groups of individuals in connexion with the production, distribution and withholding of materials for use. When politicians talk of the "mysterious disease of unemployment" they are implying that they do not understand the nature of the relation of groups of human beings among themselves, that keeps one section in idleness and withholds consumable goods from it; they do not understand how the actions of one group of people are

preventing another group from earning its daily bread. Thus by calling it a *mysterious disease* they throw the responsibility for their ignorance on to the shoulders of some supernatural agency.

But human beings in their active relations with each other do not make history in a vacuum. It is in organized working at the material world, dragging its treasures from the earth, and in what human beings do with the results of that labour and do to each other in the process, that history emerges. Thus there are initially two sets of factors of prime importance that point the course of history of any great group of human beings. For convenience we will refer to them as *environment* and *relations*. Let us examine these two separately in detail and later see how they interact with each other.

Environmental factors cover what might be called the natural resources of the soil, and all that has come from it as a result of the application of human labour in the form of skill in craftsmanship and organization. It is the milieu in which people work and live. They include also the climatic conditions of the area under consideration. Thus we may say that the history of Britain has been *conditioned* (I use the word deliberately since it canalizes, or conditions, what human beings can do with the part of the world at their disposal) by the presence of coal and iron in large and in accessible quantities, and with a climate that made it possible to work these minerals. The social life that would consequently arise in Britain would necessarily be closely bound up with the working of these minerals, *once it had become possible to utilize them*. The history of Iceland or of Canada or of Australia on the other hand was conditioned by their special resources, fishing in the case of Iceland, and grain and land cultivation generally in the case of the others. A country with a rich store of natural resources is potentially a wealthy country, however that wealth may be distributed among the population. It may nevertheless remain poverty-stricken if these resources are not developed. That, as we shall see, is a matter of organization in production and distribution and a very important one. For the *relations* that men enter into with each other, relations invariably sealed down by law, will fix whether or not the natural resources of any area can be turned to the maximum advantage of man. Other factors will contribute, but this is fundamental.

Relational factors are the arrangements that are made in the community among its members to develop the natural resources. The feudal system, although not usually seen in that light, was such an arrangement. There, where the particular natural resource that was developed was the fertility of the soil, the serf was bound to perform certain duties in this scheme for the lord of the manor. The product of the soil belonged by law to the baron, since the soil belonged to him, to lie undeveloped or to be cultivated as he thought fit. Thus he or his bailiff decided, so much for grain cultivation, so much for fruit, so much for vegetables, and so much to be kept untouched for hunting. The product of the forest, the game and the deer, were again the personal property of the baron, and he who broke this law of property would pay forfeit with his ears, his hand, or even his life.

Such mutual relations between worker and proprietor, between those who by law owned the natural resources and the tools, and those who applied their craftsmanship to them, largely determined what kind of society would emerge.

For among other things, it settled the nature of the leisure of the various levels of society. It meant that the serf had to devote any spare time he could find to eking out a bare existence from the small piece of soil he was allowed to cultivate for his own use and out of which he had again, by law, to pay his tithes to the church fathers. On occasion when the head of the family was called away, according to his legal duty, to fight the battles of his lord abroad, or on whatever marauding expedition he cared to undertake, the carrying on of the duties of the estate fell on the young members of the family. It implied for the baron and his retinue that they could devote themselves to the art of hunting and horsemanship and to the enjoyment of a certain level and quality of cultural life. To the peasant it implied a life of bondage. It implied a sharp demarcation in social class, and a drastic conditioning through the circumstances of his mode of life, that created in him a characteristic set of values profoundly different from those of the dominant class.

Such internal arrangements that have gradually been evolved to cater for the needs of the community, what we have called the relational factors, have changed periodically in history, sometimes

drastically, and within this past century or two taken on a distinctly interesting form. To appreciate its peculiar nature, and indeed its temporary character, we should constantly bear in mind the corresponding system during an earlier period, say that indicated during feudal times. This will set up for us and sharpen the necessary contrast between the two situations. It will succeed in this way in placing the modern stage in its historical perspective.

It is well recognized that an enormous part of the legal systems of most Western countries is bound up with the rights of property, and the penalties for infringement of these rights. One of the rights possessed by property holders, particularly those who hold property in land, factories and machinery, as distinct from personal property which every one possesses in some degree, is to engage in the business of supplying the community with its needs. They also have the means to undertake this task. For this purpose they are allowed to call in executive officers, workers of all kinds, who, for salaries and wages, strive to extract the natural resources of their own countries and such other available parts of the world as they find profitable, and convert them, by manufacture, into saleable commodities. In these ventures into the distant corners of the earth in the search mainly for appropriate raw materials, the States, of which these people are citizens, afford them the necessary protection by police, army, navy and air force to carry through their enterprises.

Two consequences follow from this. In the first place the States concerned are continually becoming embroiled in diplomatic exchanges, military matters and trade rights with the inhabitants of these distant countries and with other States also affording protection to those of their citizens who are pursuing the same ends. From this arises a great deal of the foreign policy of individual States, although politicians may not themselves be conscious of the mainspring of their policy.

The other consequence follows from the way in which the proceeds of these ventures are distributed. Let us remember that in Western Europe all industry is carried through by large or small groups of private entrepreneurs for the purpose of making a profit. They may argue that incidentally they also succeed in carrying on the world's work, in catering for the needs of men and in seeing that

they are adequately distributed. That, however, remains to be examined. What we do know is that broadly speaking ventures are not undertaken unless they are likely to show a profitable return.

What is meant by a profit? The answer to this can be seen if we will examine what happens to the flow of commodities that are actually produced. Taking workers and executive officers as a class, they account for a certain proportion. The wages and salaries they receive enable them in the mass to repurchase a proportion of what they have produced in the mass. If their wages and salaries enabled them to repurchase all of what has been produced, there would be no profit. It is the surplus whose existence is an essential feature of this form of production that we usually call the profit.

There is one qualification on this to which we must refer if only to remove a possible obscurity. Many of the things which are produced are not in fact consumption goods in the ordinary sense but capital goods, machinery and the like, which go back into industrial production for enhancing and improving output. The effect of this is to multiply the output of commodities and hence at the next stage to increase the volume of goods that corresponds to the profit.

Let it be clearly understood once more that we are not concerned with any moral judgment. We are not, at the moment, asserting the rightness or wrongness of this profit. All that is important for us in our understanding of the process at work, is to recognize the existence of this surplus and to answer the question—what happens to it? It is obvious from what we have said that it cannot be purchased by the workers and the executive officers. It cannot be consumed within the country of its origin. For that to happen the wages and salaries would be required to be raised to such a point, that there was no profit. It cannot be used for raising the standard of life of the inhabitants of the country of its origin. *There cannot be an internal market for it.*

It is here that we may show a distinction between a Capitalist and a Socialist State. A Capitalist State uses this surplus for profitable sale in an external market. It cannot control this market. It rises and falls in a mysterious way. It has booms and slumps, and the ingenuity of the capitalist at home has to be directed towards anticipating these fickle happenings—the accidents and irregularities of international

trade and commerce. He is, moreover, at the mercy of other factors that may involve him in difficulties. Britain is not the only industrial capitalist country of the West or of the world. There is also France, the United States of America and there is Germany. All of these are in the same position. Each has its profit surplus which it must sell on the external market and each competes with the other in these sales. If for any reason, historic or otherwise, one or other has a monopoly or a privileged position in such a market, intrigues, struggles and finally State interference may begin to make themselves apparent.

A socialist country has no such problem. Its market is clear and definite. It is internal. It plans in advance what is to be the standard of life of its population within the next few years and this settles the magnitude and the detailed form of its market. It has no profit surplus. It does not require an external market. It need not come into conflict with other commercial rivals or other States for the sale of its goods outside.

All this is, of course, over simplified. There is no country in the world, socialist or capitalist, which possesses all the raw materials required for its development and for the production of the goods its population needs. A certain exchange of commodities and raw materials is therefore essential, but the nature of this exchange is fundamentally different from the nature of the profit surplus to which we have referred.

For fully a century or more this process of profit accumulation has proceeded apace, leading first to the development of colonies, to the exploitation of their raw material and the use of the rather inefficient labour power of their inhabitants, and latterly to the further investment of the resulting profit surplus into industrial undertakings in such places as the Argentine and South America and other parts of the world not directly under the control of the State within which dwell the body of investors. This stage of the development is usually referred to as that of finance capitalism.

For fully a century this process has proceeded with ever-increasing acceleration.

Not all of these ventures can be regarded as profitable, however, and certainly far from all as socially valuable. Bankruptcies and loss

of capital have occurred regularly alongside the expansion of capital rights, and particularly during the last twenty years there have been periodic epidemics of bankruptcies and collapses of one kind and another. A period of instability has set in, that suggests the end of the epoch of capital expansion.

This is roughly the system of relations that has now been brought into being in most countries, for the historic purpose of applying the natural resources of the world to the benefit of mankind. Viewed dispassionately it is a peculiar and an interesting scheme. As it develops it succeeds in arousing new needs and desires in the populations of the world. In perspective we can see that it will survive so long as it is able, broadly speaking, to satisfy the needs it arouses.

The ruthlessness of the process from one point of view cannot be called into question. Vast stretches of countryside have been denuded of greenery that the valuable minerals, coal, iron, oil, copper, tin, diamonds and gold, may be wrested from the bowels of the earth. Populations have flocked from agricultural areas into the manufacturing and mining centres to play their part as executive officers in the process. They have settled down, reared families, and established new forms of social life as if this latest human venture was something static and permanent. Congested areas and slum towns have sprung up, inhabited by blasé and sophisticated town dwellers, the grandchildren of simple peasants. During the past century the new industrialism has brought into being empires, navies, trade unionism, the co-operative movement, the political labour movement and all the paraphernalia of democracy and its safeguards. Man's historic struggle with nature for the creation of freedom has thus taken on a new complexion in the efforts to master the problems of the new situation. Men have thought the thoughts of their period, striven to satisfy the new needs and desires evoked, and have expressed their aspirations in terms of them. In institutions and in movements, political, educational and ethical, they have represented them in social forms.

At the beckon call of industry, science and technology have been raised to a new activity, and their discoveries have been turned to the fashioning of marvellous contrivances to relieve boredom, to increase production, to provide the material for new artistic forms

and eliminate unnecessary labour. In two generations the face of the world and the minds of men have changed profoundly. Time and space have been bridged and man has acquired a grasp of the material aspects of the universe to an extent previously undreamt of.

In the slow-changing East, new colonies, dependencies, and empires have arisen rapidly, the private property of the investors of the feverishly developing West. In the wake of this process the last century has seen more wars, punitive expeditions, and raids, and on a greater scale than in any corresponding stretch of time in previous history. Thus the war of 1914–18 can be recognized as one stage, if not the climax, of a process that has been germinating in the womb of the industrial system for this past hundred years; while we poor creatures, victims of a situation which none of us seem yet able to control, pretend to explain an historical phase in terms of an accidental shot at Sarajevo or of "rights and wrongs" of this or that petty detail. If, therefore, we are to take account of the successes of the great industrial revolution of the past hundred years, side by side with them must be placed the costs in the form of human exploitation and intricate political complications, that follow from the extension of the Western conception of property rights, and the partial extension of the Western legal system, to the countries of the East.

But there is an aspect of all this to be examined in greater detail if we are to acquire a basis on which to rest our political principles. There is the problem of consumption or distribution of the proceeds of all this feverish activity. Now it is worth while bearing in mind that if man's purpose is indeed consciously to reap the fruits of the earth for his benefit, the detailed distribution of these fruits would not necessarily depend on the organizational methods used in production. The relational factors we have introduced, however, make this impossible as it stands.

The groups who share directly in these proceeds consist first, of those who hold the legal rights to the original property (usually in the form of shares), and secondly, of those who have been engaged as executives in some capacity. By the use of tokens, notes, cheques and coins, a most interesting and valuable invention by man, it becomes possible to transfer claims to goods, from one person to

another, i.e., to exchange and sub-divide claims. In this way an individual may distribute his claims to production over a variety of commodities.

Members of the community not needed to carry on the process of production become, on this scheme, unnecessary. They have no legal claims to the proceeds and therefore no legal claims to the tokens. As far as the relational side is concerned, these individuals are simply frozen out of the circle of production and consumption. They are elbowed out of the community. But a community cannot survive by self-destruction. To meet this contingency, accordingly, State schemes of industrial insurance, and unemployment pay of sorts are introduced. This has come into being in the effort to take up some of the enormous slack left by our peculiar methods of catering for communal needs. In our day the scale of international unemployment is one measure of the inability of the system to carry through the task history demands of it. Unemployment is loose-jointedness. The history of developing unemployment is the history of an intensifying loose-jointedness. If the joints loosen too far the body must fall to pieces. From the chaos of this disorganization emerges most of the problems of internal politics.

To appraise all this at its proper level we have to recollect that historically this form of social organization is a comparatively new feature of communal life. True we have lived at a colossal pace, compared with our predecessors on this planet, but because of that pace the system has passed the more rapidly through its successive stages. Born and bred in it, like all creatures of their period we tend to regard it as something rooted for all time in nature. It has been in growth for certainly less than two hundred years, while the even more modern form in which finance, directing the course of events by controlling exchange tokens, has succeeded in playing a dominant role for much less than thirty years. That it will pass, as the feudal system and the mercantile period passed in their day, is obvious to any student of history. Such systems begin to collapse when the needs and desires of the community, evoked themselves by the increasing control over nature that is continually being wrought, can no longer be satisfied by any simple readjustment in the relational factors then in existence. Let us realize in any case that

relational factors are wrapped up in the rights of property, and property rights show themselves in material things, in power over others, in income and in standard of life. History shows that there are no extremes from which people will shrink in order to preserve such things. In fighting to retain their material comforts, what have become their primary needs, they conceive themselves as fighting for all that life holds dear.

It is against this background that we have to see the present struggle in Europe and its possible extension into Asia. It is a facile explanation to refer it all to the evil genius of one man, and to the brutality of the party he has at his beck and call. It is more scientific to recognize that they are largely the consequences of the application to Germany of the same industrial forces that created the British and French Empires, and that made the North American continent what it is. The early development of the British and French Empires before Germany had got into her stride necessarily created a situation that has tended to frustrate the corresponding growth of a German Empire. The degradation that came to Germany with the Nazi regime can then be seen as an almost inevitable consequence of an economically impossible position. On the other hand, the policy of Russia follows from the fact that she recognizes this need of a capitalist country for external expansion, and fears either that Germany will herself seek to obtain a colonial empire from her, or that Britain and France will unconsciously be driven to attack her in order to obtain these necessary colonies for Germany, and incidentally carve up the rest of Russia as "spheres of influence." It would naturally be exceedingly difficult for Russia to believe that the British and French Governments would follow a policy that would consciously lead to the creation of a socialist Germany as the solution to the incessant struggles among the competing powers. Nevertheless, only by the passage of Germany to a socialist economy can there be any final peace in Europe, for in such circumstances it will naturally create its market internally, and so be switched out of its external competition with industrial rivals.

This then is the background against which we have to see the actions and policies of statesmen, the struggle of trade unions and employers' federations, the co-operative movement as an attempt

to use the legal rights of private property in order if possible to ensure that property rights shall not be translated into charges on production, the struggle for political freedom from the days of the chartists to the period of the emancipation of women, the right wing political movement as the forces that would rather put a brake on change than plunge into something they fear, the left wing politicians as those who would escape from the terrors of the present by urging society to create the next stage before catastrophe befalls. Over and above all this we have to see our cultural movements, our educational system, our writers, scientists, poets, and artists—and our politicians—playing their part in this scene, coloured, mostly unconsciously, by the atmosphere in which they temporarily find themselves.

A scientific politician is one who recognizes the process through which society is passing, understands the human and material forces that drive it on from one level to the next, and therefore assesses at their proper valuation the proposals of governments.

Like all true thinkers, artists, and men of action, he will be alive to the detail, but appreciate its significance against the shifting background of history. He will see both the events and their flow, and he will therefore appreciate the part he and those like him have to play in the conscious creation of a history fit for civilized man.

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